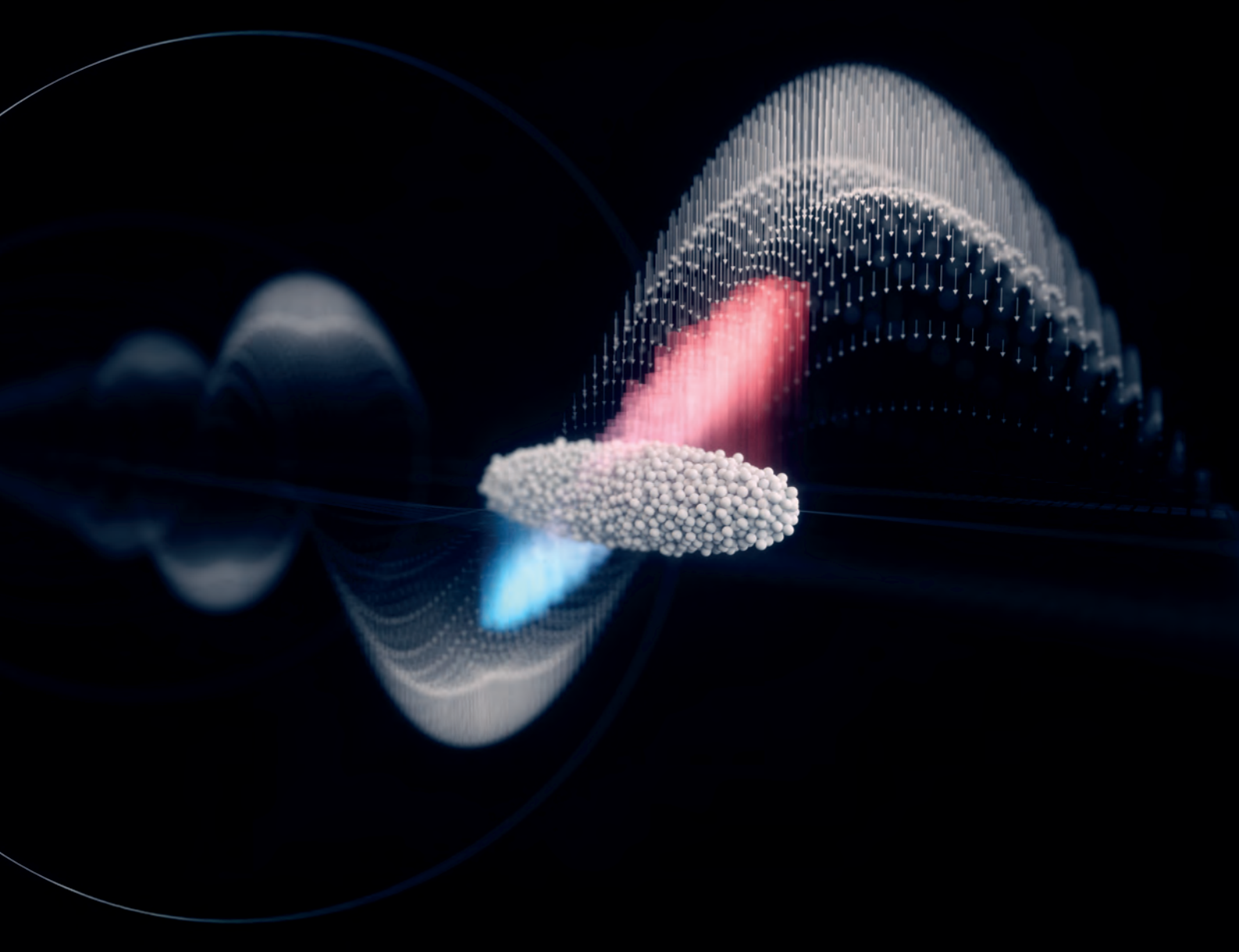




ACCELERATORS 2025.

Highlights and Annual Report

Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association





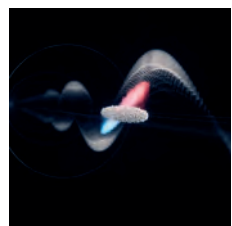
ACCELERATORS 2025.

Highlights and Annual Report

Milestone for laser plasma acceleration

Innovative laser plasma acceleration technology brings electrons up to speed in just a few centimetres, saving space, costs and energy. As an integral part of DESY's future project PETRA IV, DESY will build a compact plasma-based injector to inject 6 GeV electron beams directly into the storage ring.

DESY has reached an important milestone on this journey by demonstrating active energy compression of a laser plasma-accelerated electron beam in a proof-of-concept experiment at DESY's LUX laser plasma accelerator facility. In an active radio frequency cavity, high-energy electrons at the beginning of the pulse are decelerated, while low-energy electrons at the end of the bunch are accelerated (see p. 62).



Picture: Science Communication Lab for DESY

PETRA IV – the ultimate 4D X-ray microscope

Greater brilliance, speed and precision: DESY's planned flagship project PETRA IV, the world's most powerful 4D X-ray microscope (see p. 40), is being developed on the DESY campus in Hamburg and will be an anchor facility for the planned Science City Hamburg Bahrenfeld. PETRA IV will enable unparalleled analyses of complex materials and biological systems – from the millimetre scale down to the nanoscale. Scientists from around the world will use it to develop technologies and pharmaceutical compounds that can improve our everyday lives in the long term – from solar cells, microchips and materials for quantum computers to new types of medication.

Picture: Science Communication Lab for DESY

Contents

> Introduction	4
> News and events	10
> Accelerator operation and construction	26
> Highlights · New technology · Developments	38
> References	74

The year 2025 at DESY

Dear Colleagues and Friends of DESY

As I reflect on the year 2025, I am proud to present this annual report of DESY. It is the first time that I have the honour to do this, having started as Chair of the DESY Board of Directors on 1 April. I have very much enjoyed this first half year in my new job, most of all as every day I learn something new about DESY, and I get to work with so many talented and committed people.

In 2025, there were many changes in the Directorate: Britta Redlich started on 1 January as the new Director in charge of Photon Science, taking over from Franz X. Kärtner, who had filled this role *ad interim* for a year after Edgar Weckert’s term finished at the end of 2023.

On 1 April, Iris Wilhelm took up her position as Administrative Director. And, on 1 November, Ulrich Husemann started as new Director in charge of Particle Physics. My deep gratitude goes to the former and interim directors, Christian Haringa, Edgar Weckert, Arik Willner, Ties Behnke and in particular Helmut Dosch, for their tireless commitment to advance DESY. Together with the experienced directors Wim Leemans and Christian Stegmann, we form a team that is steering DESY – in collaboration with the deputy directors, group and team leaders, all employees as well as the members of our advisory boards and the funding agencies – through these somewhat turbulent times.



Figure 1
Ceremonial transition at DESY on 31 March 2025: Outgoing Chair of the DESY Board of Directors Helmut Dosch (right) transfers leadership to Beate Heinemann (left), with Manja Schüle (Minister of Science, Brandenburg) and Katharina Fegebank (Senator and Second Mayor of Hamburg) in attendance.



Figure 2
The DESY Board of Directors with newly appointed members in November 2025 (from left): Miriam Hufnagl (Delegate of the Directorate for Innovation, CTO (interim)), Iris Wilhelm (Director of Administration), Christian Stegman (Director in charge of Astroparticle Physics), Wim Leemans (Director of the Accelerator Division), Britta Redlich (Director in charge of Photon Science), Beate Heinemann (Chair of the DESY Board of Directors), Ulrich Husemann (Director in charge of Particle Physics)

Science faces profound challenges in today’s world. The pace of technological and geopolitical change has blurred the lines between open knowledge and strategic competition. Global crises, such as pandemics, climate change, conflicts and wars, underscore the need for international collaboration, and simultaneously trust and cooperation across borders are eroding. At the same time, the spread of misinformation and the politicisation of scientific facts threaten public confidence in evidence-based decision and policy making. Researchers must balance openness with responsibility – safeguarding integrity, transparency and security while ensuring that science continues to serve humanity as a shared, global endeavour.

DESY as a premier research institution plays an important role in the national and international science landscape. Each year, thousands of scientists from around the world

come to us to perform measurements, attend workshops and conferences or collaborate with colleagues on our sites in Zeuthen and Hamburg. We have collaborations with institutions across Europe and the entire world, and our scientists travel across the globe to advance their research.

The success of DESY is founded on the design, construction and operation of fantastic research infrastructures, on cutting-edge contributions to science, on the thriving of many scientists at all career levels, who pursue their ideas and engage in collaborations worldwide, and – above all – on the skilled and dedicated employees of DESY, who enable all this at a technical and administrative level.

This year, DESY has once again demonstrated its scientific excellence. In February 2025, a panel of international

scientists appointed by the Helmholtz Association visited and reviewed DESY. All areas of our research and of the operation of our facilities were rated with the highest marks, and many useful recommendations were given for the next funding period of the Helmholtz Association's programme-oriented funding (PoF V). The panel was also impressed by our activities in the areas of diversity, international cooperation, sustainability, innovation and talent development. Later in the year, we were thrilled that six Clusters of Excellence with DESY contributions were selected for funding by the German Research Foundation (DFG), and at the European level one European Research Council (ERC) Starting Grant and two Synergy Grants were awarded.

A major achievement this year has been the completion of the upgrade project FLASH2020+. The implementation of external seeding and the newly installed variable-gap undulators will significantly enhance the capabilities of our FLASH free-electron laser facility, so that it remains at the

forefront of extreme ultraviolet and soft X-ray science. In Zeuthen, a key accomplishment has been the completion of the construction of new sensor modules (mDOMs) for the upgrade of the IceCube neutrino detector at the South Pole: 201 mDOMs were shipped to Antarctica to be installed there during the Antarctic summer. In the second half of 2025, the European XFEL accelerator was warmed up for the first time since its start-up in 2017 to allow the mandatory inspection of helium valves, perform maintenance tasks and install a new electron source at the beginning of the accelerator, which was newly developed at DESY's photoinjector test facility (PITZ) in Zeuthen.

2025 has also seen DESY at the forefront of critical political and strategic initiatives. The selection of our two future projects, IceCube-Gen2 and PETRA IV, in the "National Prioritisation Process for Extensive Research Infrastructures", alongside seven other large research infrastructures in Germany, underscores our important role in shaping the national and European research agendas. In 2026,

we expect to get the final go-ahead for the PETRA IV project and continue to advance the detailed planning, with the goal of delivering the project on time and on budget.

It is particularly important to attract young talents to DESY. At any time, we have about 130 apprentices, 250 doctoral students and 250 postdoctoral researchers at DESY. Among the PhD students and postdoctoral researchers, about two thirds are not from Germany, and our International Office plays a key role in ensuring that these young people are supported during the first weeks, so that they quickly feel at home. This year, we also welcomed three new Lead Scientists, who bring fresh perspectives and expertise to DESY: Elina Fuchs in theoretical particle physics, Samaya Nissanke in gravitational and multi-messenger astrophysics and Nønne Prisle in physical chemistry and aerosol research.

Innovation is a very important part of DESY's mission. We want to contribute to ensuring that science also results in making life better for society at large. The successful participation in the Startup Factories competition of the Federal Ministry for Economic Affairs and Energy, resulting in the "Impossible Founders", which strengthen the innovation ecosystem in Hamburg, as well as our strategic cooperation with the Fraunhofer-Gesellschaft exemplify our commitment to translating research into practical applications. These collaborations, along with our many regional, national and global partnerships with industry partners and academic institutions, position DESY as a leader in both scientific and industrial innovation.

Our campuses in Hamburg and Zeuthen continue to evolve. We had three topping-out ceremonies this year, celebrating the structural completion of the Centre for Accelerator Science and Technology (CAST) building and the two DESY Innovation Factory buildings. The new visitor centre DESYUM in Hamburg will open in spring 2026. Together with our campus partners, we are striving to make our campuses more sustainable and greener, and we have been awarded prizes this year: for the roof terrace of the Max Planck Institute for the Structure and Dynamics of Matter and the DESY Building 36, a big hall from 1977 on the Hamburg campus.

In an increasingly interconnected world, international collaboration is more important than ever. Our partnerships with institutions such as the SESAME synchrotron light source in Jordan and our engagement in science diplomacy reflect our belief in the power of global cooperation. As we navigate geopolitical challenges, DESY remains committed to fostering transparency, exchange and collaboration on both local and international levels.



Figure 4
Impression of the roof of DESY's award-winning Building 36

In closing, I would like to express my gratitude to the entire DESY community – our experienced and early-career scientists, engineers, technicians, administrators, users and partners – for their dedication and hard work. My special thanks go to the funding agencies – the Federal Ministry of Research, Technology and Space (BMFTR) and the Science Ministries in Hamburg and Brandenburg (BWFG and BMWK) – which have been supporting DESY for many decades. I would also like to extend my heartfelt thanks to Helmut Dosch for his outstanding leadership and long-standing commitment to DESY, which have laid the foundations for much of what we are building on today. Together, we continue to push the boundaries of knowledge and innovation, ensuring that DESY remains at the forefront of global research.

Warm regards,

Yours Beate

Beate Heinemann
Chairperson of the DESY Board of Directors



Figure 3
Celebrating a milestone for German science: On 8 July 2025, DESY employees gathered in the auditorium to mark the BMFTR's decision to prioritise IceCube-Gen2 and PETRA IV as key research infrastructures. In the front row (from left): new directors Iris Wilhelm and Britta Redlich.

Accelerators at DESY

Introduction

Dear colleagues
and friends,

The past year has been one of momentum, transition and tangible progress across DESY’s accelerator landscape. It was a year in which long-term vision has increasingly taken concrete shape – both in our major facilities and in the technologies that will define the next generation of accelerators.

A central milestone has been the continued advancement of DESY’s flagship project, the next-generation X-ray source PETRA IV. With its recognition as a research infrastructure of national importance and significant progress in its conceptual and technological development – including innovative plasma-based injector concepts – PETRA IV is moving steadily from vision to reality. At the same time, research into compact plasma accelerators has achieved important breakthroughs, from improved beam quality at the LUX experiment with active energy compression to higher repetition rates with the KALDERA high-power laser, underlining their potential as future building blocks for large-scale facilities.

Meanwhile, the DESY II synchrotron – the pre-accelerator (booster) for the PETRA III storage ring – celebrated 40 years of beam operation, underscoring that the PETRA III accelerator chain is coming of age and that the time for an upgrade has clearly arrived.

At the FLASH free-electron laser (FEL) facility, a major chapter has been completed with the successful restart following the FLASH2020+ upgrade. The new capabilities



Figure 1
PETRA IV is gaining momentum as a research infrastructure of national importance, setting the stage for the next generation of discovery.

– externally seeded operation, enhanced stability and unprecedented spectral control – open up entirely new experimental possibilities. This progress is rooted in 25 years of FEL development since the first lasing at the TESLA Test Facility (TTF) – today known as FLASH, a legacy that continues to shape the global FEL landscape. With the FLASHForward experiment, DESY continues to pioneer plasma wakefield acceleration, advancing beam quality and stability towards applications in next-generation accelerators.

The European XFEL X-ray laser has likewise taken important steps forward. During its first major long shutdown, key upgrades were implemented, including a new high-performance electron source, upgraded cryogenic valves and preparations for future enhancements. Combined with scientific breakthroughs – such as the lasing of a cavity-based X-ray FEL or advances in accelerator control achieving attosecond-level precision in superconducting cavities – these developments will further strengthen the facility’s role as a leading international research infrastructure.

Beyond the large facilities, the year has been marked by innovation at many levels. The successful demonstration of AI-based accelerator tuning using large language models, advances in control systems and new approaches to simulation and feedback illustrate how rapidly the field is evolving. At the same time, strategic collaborations – with partners such as the Fraunhofer-Gesellschaft and through initiatives such as Hi-Acts and the Hamburg International Centre for Accelerators, Photonics and Entrepreneurship (HICAPE) – are accelerating the transfer of these developments into broader applications, fostering collaboration and boosting visibility.

Infrastructure and environment are evolving in parallel. With the foundation stone and topping-out ceremonies for the new Centre for Accelerator Science and Technology (CAST), a future hub for accelerator expertise is taking shape at the heart of the DESY campus in Hamburg. The development of the DESY Innovation Factory, the DESYUM visitor centre and the growing ecosystem of the Science City Hamburg Bahrenfeld further underline DESY’s role as a driver of innovation, collaboration and regional impact.



Figure 2
It was a particular pleasure for me to contribute – together with my colleagues from the accelerator control room, Jürgen Haar and Arne Brinkmann – to the filling of the time capsule for the CAST foundation stone ceremony, leaving a small legacy for the future. We were also honoured by the presence of Eva Gumbel, State Councillor for Science, Research and Gender Equality of the City of Hamburg, who highlighted the importance of CAST for the development of the Science City Hamburg Bahrenfeld in her speech (pictures: Jens Rothenburg, DESY).

This progress is inseparable from the people who make it all possible. From recognition with numerous awards and prestigious European Research Council (ERC) Synergy Grants to the new doctoral network EPACE and a vibrant international summer student programme, the breadth and depth of expertise across the research centre remain one of our greatest strengths and reflect not only individual excellence, but also the strength of our collaborative culture. Initiatives in career development, such as the COAST career centre for postdocs, along with diversity efforts continue to foster an open and forward-looking research environment.

The year also marked a transition in leadership and significant changes within the DESY Directorate. Most notably, after more than 16 years, Helmut Dosch concluded his term as Chairman of the DESY Board of Directors and handed over the baton to Beate Heinemann. As Helmut has entered retirement, his influence on DESY’s trajectory remains clearly visible – visionary, bold and ambitious, an amazing legacy that lays the foundation for the decades to come, particularly reflected in his unwavering commitment to bringing PETRA IV to fruition.



Looking towards the future, DESY remains firmly committed to advancing science for the benefit of society – through discovery, innovation and collaboration across disciplines and borders. With strong scientific foundations, advancing technologies and a vibrant international community of partners around the world, we continue to work towards our shared goal: enabling discoveries that expand our understanding of the world and contribute to addressing the challenges of the future.

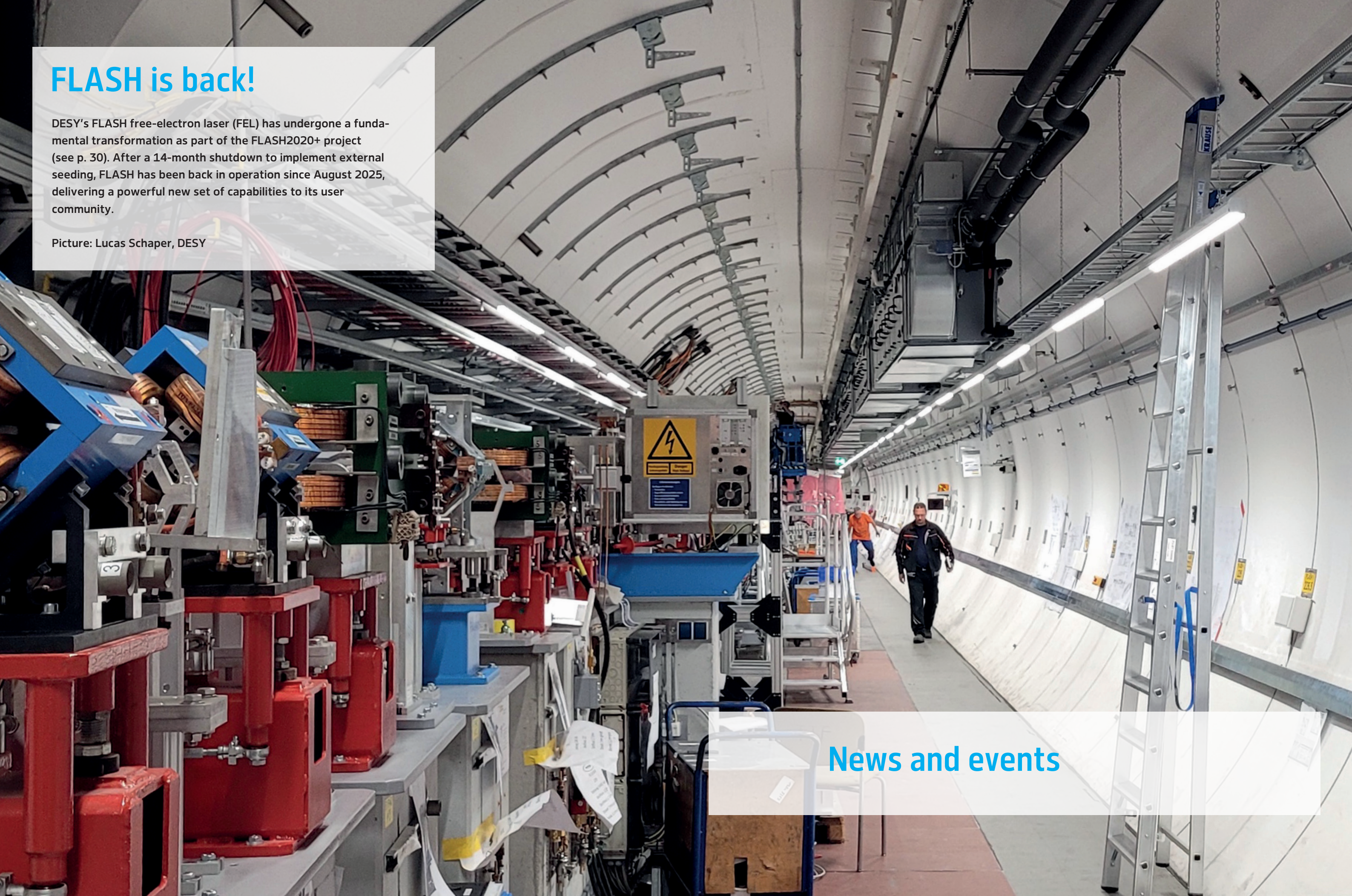
In a world increasingly shaped by uncertainty, the pursuit of knowledge, the integrity of information and the openness of scientific exchange are more essential than ever as foundations for informed decisions, resilience and progress. As the saying goes: “When the going gets tough, the tough get going.” Let’s take this on together!

Wim Leemans
Director of the Accelerator Division

FLASH is back!

DESY's FLASH free-electron laser (FEL) has undergone a fundamental transformation as part of the FLASH2020+ project (see p. 30). After a 14-month shutdown to implement external seeding, FLASH has been back in operation since August 2025, delivering a powerful new set of capabilities to its user community.

Picture: Lucas Schaper, DESY



News and events

News and events

A busy year 2025

January

Foundation stone laid for new CAST accelerator building

On 17 January, DESY laid the foundation stone for its new Centre for Accelerator Science and Technology (CAST) on the DESY campus in Hamburg. CAST will provide 2400 square metres of office space, meeting rooms and an accelerator control room in the middle of the campus to about 240 employees from DESY's Accelerator Division. The new research building includes meeting areas to foster interaction to promote everyday encounters and the spontaneous exchange of knowledge. A special highlight for visitors: From a separate room, they will be able to look directly into the heart of the building – the accelerator control room – and feel the “DESY pulse”. This is where researchers, engineers and technicians will work together to control the operation of DESY's accelerators safely and efficiently. CAST will open its doors to employees in 2026 and will also serve as a meeting place for guest researchers and visitors.



Visualisation of the CAST building

Over 1100 participants at joint Users' Meeting



ChatGPT, run my particle accelerator!

It has become common practice to consult artificial intelligence (AI) on a wide range of topics and problems. Scientists at DESY and Universität Hamburg have now demonstrated that AI, including ChatGPT-like large language models (LLMs), can help operate and optimise a particle accelerator. In a study published in *Science Advances*, researchers used 14 LLMs to control DESY's ARES linear accelerator by adjusting key parameters through natural language prompts rather than traditional coding. Some models performed remarkably well, highlighting the potential of LLMs to solve complex optimisation problems beyond accelerator physics. While challenges remain – such as high

Participation was high once again in the joint DESY Photon Science and European XFEL Users' Meeting 2025 in Hamburg. More than 1100 scientists registered to discuss the latest research performed at DESY's X-ray light sources PETRA III and FLASH as well as at the European XFEL X-ray laser. Over the course of the three-day event, participants learned about new developments and prospects. The jointly organised meeting is the largest gathering of its kind worldwide.

computational demands and performance limitations compared to specialised methods – the study marks an important step towards more intuitive, AI-assisted operation of advanced scientific facilities.



February

Talks on innovation and transfer at DESY in Zeuthen

During a visit to DESY's Zeuthen site, Michael Kellner, Parliamentary State Secretary at the Federal Ministry for Economic Affairs and Climate Action (BMWK), gained insight into research with strong societal impact. Highlights included accelerator developments such as the PITZ facility, supporting the European XFEL, and medical innovations such as *FLASH* radiation therapy. DESY also presented its work in quantum technologies and its collaboration with industry to strengthen innovation. Kellner praised DESY's technological expertise and regional impact, emphasising the importance of research, technology transfer and training for future-oriented innovation.

Technology transfer in focus at DESY in Hamburg

Hamburg's Senator for Economic Affairs Melanie Leonhard visited DESY to learn about innovation activities at DESY and in the Science City Hamburg Bahrenfeld, which will be a centre for scientific research and technology transfer in the future. Of particular interest were examples of collaboration with industry and DESY's support for startups.



Hamburg's Senator for Economic Affairs Melanie Leonhard (left) on her visit to DESY

Fraunhofer and DESY launch strategic collaboration to promote innovation and research

DESY and the Fraunhofer-Gesellschaft launched a strategic collaboration to strengthen innovation, technology transfer and industrial competitiveness. Fraunhofer stands for applied research and the transfer of technology, while DESY develops and operates leading infrastructures that serve as catalysts for technology develop-

ments and innovation processes. By combining DESY's world-leading research infrastructure – such as PETRA III and its planned successor PETRA IV – with Fraunhofer's applied research expertise, the partnership aims to accelerate the translation of scientific discoveries into practical applications.



From left: Britta Redlich, Arik Willner and Helmut Dosch from DESY signed the collaboration agreement with Holger Hanselka, Axel Müller-Groeling and Katja Seidel from Fraunhofer.

"Jugend Forscht" gives kids' research a chance at the national stage

DESY hosted the regional round of the "Jugend forscht" science competition – which celebrated its 60th anniversary – for the 13th time, bringing together pupils to present innovative research projects across diverse fields. Held at DESY's School Lab in Hamburg, the competition showcased topics from artificial intelligence and robotics to climate research and social sciences. The event highlights DESY's commitment to supporting young talent and fostering the next generation of scientists.



March

Launch of doctoral network EPACE focusing on compact accelerators

The European Compact Accelerators, Their Applications, and Entrepreneurship (EPACE) doctoral network secured funding from the prestigious Marie Skłodowska-Curie Actions, the EU's leading programme for doctoral education and postdoctoral training. EPACE aims to train the next generation of scientists in compact accelerator technologies while exploring their applications and commercial potential. The consortium is coordinated by Maxence Thévenet, team leader for theory and simulation in DESY's Plasma

Acceleration group. It comprises nine academic institutions and one private company across seven EU countries, alongside 22 associated partners worldwide. The four-year EPACE programme will support 15 PhD projects, combining cutting-edge research, scientific education and international secondments with strong industry collaboration and entrepreneurship training. The aim is to accelerate technology transfer and prepare a new generation of experts in compact accelerator technologies.



Nine academic institutions and one private company collaborate within the EPACE network to conduct innovative research and train the next generation of physicists.

Foundation stone laid for DESY Innovation Factory in Altona Innovation Park

The foundation stone for DESY's Innovation Factory in the Altona Innovation Park was laid on 26 March, marking an important and symbolic milestone in the development of the Science City Hamburg Bahrenfeld. From 2027, the facility will provide modern laboratory and office space for startups in high-tech fields, strengthening collaboration between science and industry. The project supports innovation, technology transfer and Hamburg's ambition to become a leading hub for future technologies.



Foundation stone ceremony in the presence of Hamburg's Senator for Economic Affairs Melanie Leonhard (third from left) and Hamburg's Senator for Science Katharina Fegebank (fifth from left)

April

Tschüss Helmut. Moin Beate.

On 1 April, Helmut Dosch, who had been leading DESY for more than 16 years, handed over the Chair of DESY's Board of Directors to Beate Heinemann. A professor at Universität Hamburg, she had previously served as a member of the Directorate in her capacity as Director in charge of Particle Physics and is the first woman to head the research centre. Also on 1 April, Iris Wilhelm took over as Administrative Director at DESY.



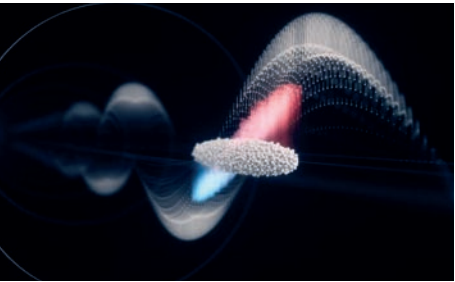
Helmut Dosch hands over the DESY master key – and with it, the management – to Beate Heinemann.

DESY's flagship laser KALDERA accelerates first electrons

Laser plasma accelerators can accelerate particles over distances that are up to 1000 times shorter than those required by conventional accelerators. The technology promises compact systems that have enormous potential to open up new applications for accelerators, for example in medicine or industry. However, the current prototypes have one drawback: Most can only accelerate a few particle bunches per second – not enough for practical applications. DESY's new flagship laser KALDERA now made a decisive step forward: Driving the compact plasma accelerator MAGMA, the innovative laser was shown to accelerate 100 particle bunches per second. This represents a significant increase in repetition rate compared to earlier prototypes and addresses a key challenge in making compact plasma accelerators viable for real-world applications. →

Milestone for laser plasma acceleration

Laser plasma acceleration is a potentially disruptive technology: It could be used to build far more compact accelerators and open up new use cases in fundamental research, industry and health. However, on the path to real-world applications, some properties of the plasma-driven electron beam as delivered by current prototype accelerators still need to be refined. DESY researchers have made a major advance in laser

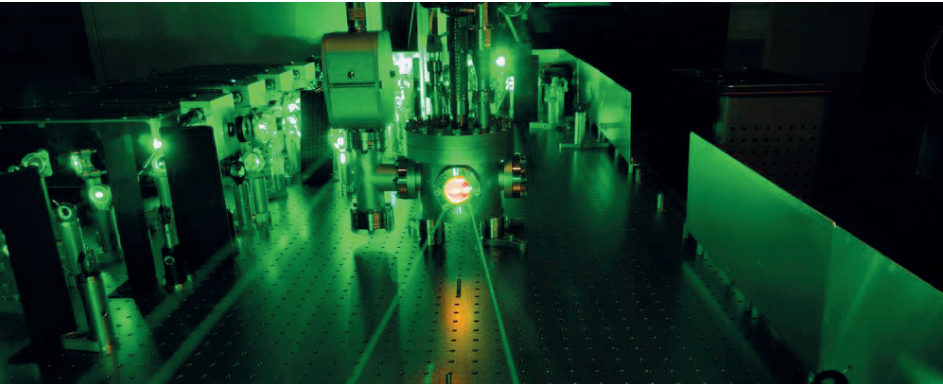


Energy compression of a laser plasma-accelerated electron bunch in an active radio frequency cavity: High-energy electrons at the beginning of the pulse are decelerated, while low-energy electrons at the end of the bunch are accelerated.

→ The higher repetition rate is particularly important as it enables active stabilisation of the accelerator. Using sensors and feedback systems, fluctuations caused by environmental factors can be corrected in real time, leading to more stable and higher-quality electron beams. Such stabilisation is essential for applications such

plasma acceleration by significantly improving the quality and stability of electron beams at the LUX experiment. Using a two-stage correction system that combines a magnetic chicane and a radio frequency resonator, the team was able to greatly reduce the energy spread and fluctuations of the accelerated electron bunches, achieving beam properties comparable to those of conventional accelerators. The results were published in *Nature*.

The breakthrough addresses a key challenge of plasma-based acceleration and marks an important step towards real-world applications. In particular, it opens up the possibility of using compact plasma accelerators as injectors for large-scale research facilities, such as PETRA III and its successor PETRA IV, highlighting plasma accelerators' potential as more compact and efficient alternatives to traditional accelerator technology.



Amplifier of the KALDERA laser system: The laser energy is increased by transferring energy of green pump laser pulses to the KALDERA laser pulses.

May

"Every brain is unique": European XFEL and DESY host neurodiversity panel

Embracing diversity at all levels, DESY and the European XFEL jointly hosted the neurodiversity event "Every brain is unique". The event, which included a keynote lecture by a chief physician and a panel discussion, raised awareness of the challenges that neurodivergent colleagues face in their daily work and also highlighted some of the special abilities of neurodivergent people: unique problem-solving skills, creativity and innovative potential.



Participants and organisers of the neurodiversity panel

Four Clusters of Excellence with DESY involvement in Hamburg

As part of the Excellence Strategy of the German federal and state governments, Universität Hamburg was awarded four Clusters of Excellence and the Hamburg University of Technology one. DESY is involved in four of these Hamburg-based Clusters of Excellence, which will receive funding from 2026 on.



May

Hamburg's Science Senator Maryam Blumenthal visits DESY

Maryam Blumenthal, Hamburg's new Senator for Science, Research and Equality, visited the DESY campus for the first time in her new role on 19 May. During a guided tour, she gained insight into the experiments at PETRA III, a preview of how its successor PETRA IV will drive new discoveries for science and applications as well as an over-view of the innovation ecosystem.



From left: Hamburg's Senator for Science Maryam Blumenthal took a tour of the campus together with DESY Directors Iris Wilhelm and Beate Heinemann as well as Hans-Christian Wille and Michaela Schaumann from the PETRA III team.

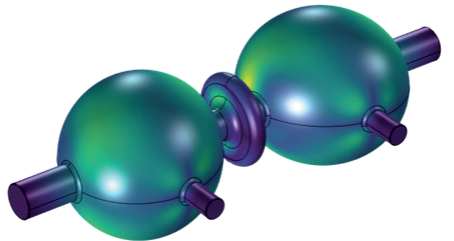
Next round of "Science on Tap" in Hamburg's bars and pubs

Are we immersed in dark matter? How do you reveal 5000-year-old secrets in letters? Is climate protection a private commitment or a national goal? And does the language I use influence my identity? At the yearly "Science on Tap" event, researchers from Universität Hamburg and DESY once again provided answers to exciting and topical questions in Hamburg's bars and pubs.



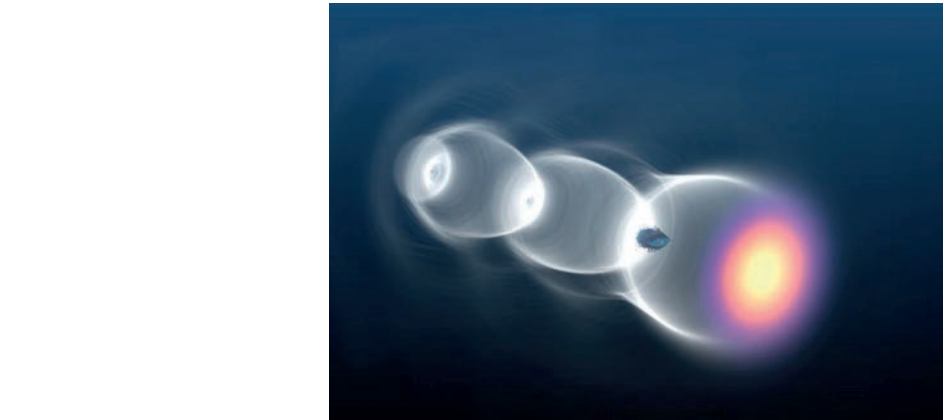
June

Gravity cavity: Searching for gravitational waves



Visualisation of the characterised cavity

An international collaboration led by DESY revived a former exhibition cavity to explore a novel method for detecting gravitational waves. In partnership with Universität Hamburg and Fermilab in the USA, the refurbished superconducting cavity is to be used to study how tiny frequency shifts could reveal passing waves or axions – offering an alternative to large-scale experiments such as LIGO, a large laser interferometer in the USA. Following repairs, detailed characterisation and low-temperature testing, first measurements with the cavity were planned in Hamburg. The work serves as a key step towards the future SHOGWAVE experiment (see p. 72), which aims to develop a dedicated system for more sensitive gravitational wave detection.



In the laser plasma accelerator, a short, high-intensity laser (shown in yellow) generates a plasma wave (shown in white). This wave makes it possible to accelerate electron bunches (shown in blue) to the energy required for PETRA IV within a few centimetres.

July

Conceptual design study for innovative plasma injector

Large particle accelerators are highly complex machines. At DESY's X-ray source PETRA III, electrons travelling close to the speed of light are stored for many hours. This process requires an injector – a complex assembly of pre-accelerators that first produces the particles and then brings them up to speed before they are injected into the 2.3-kilometre PETRA III electron storage ring. For its planned successor PETRA IV, an innovative laser plasma accelerator is being developed that will inject the electrons directly into the storage ring without the detour through a pre-accelerator chain. This would save space and energy. In a recently published conceptual design report (CDR), DESY outlines this approach.

The study highlights key advances, including an energy compression stage to reduce electron energy spread and a plasma channel-guided accelerator for higher energies. While challenges remain – particularly in terms of beam quality, repetition rate and reliability – parts of the concept have already been proven in initial trials. A prototype demonstrator is planned by 2026 to test plasma-based injection at PETRA III, marking an important step toward integrating compact plasma technologies into large-scale facilities.

PETRA IV: Acceleration for Europe from Hamburg

The "Prioritisation procedure for extensive research infrastructures" of the Federal Ministry of Research, Technology and Space (BMFTR) ended with a bang: On 8 July, Federal Research Minister Dorothee Bär announced that both projects submitted by DESY

were classified as research infrastructures of national importance. The X-ray light source PETRA IV and the neutrino telescope IceCube-Gen2 were thus attested high scientific excellence, innovation and transfer potential as well as well thought-out planning.



From left: Director in charge of Photon Science Britta Redlich, Chairperson of the DESY Directorate Beate Heinemann and Director of the Accelerator Division Wim Leemans with a model of the experimental hall for PETRA IV

"Impossible Founders": Hamburg's new deep-tech startup factory

Hamburg was selected as one of ten winners in the federal "Startup Factories" competition, securing 10 million euros in funding from the Federal Ministry for Economic Affairs and Energy, complemented by a further 40 million euros from regional partners. The new Hamburg startup factory, "Impossible Founders", will support deep-tech

spin-offs from science, with a focus on green technologies, AI and new materials. With strong involvement of research institutions such as DESY, the programme aims to accelerate the transfer of scientific results into market-ready innovations and strengthen Hamburg's position as a leading hub for technology-driven startups.



The "Impossible Founders" team celebrates its success in the "Startup Factories" competition – seen here after the award ceremony together with Katherina Reiche, Federal Minister for Economic Affairs and Energy (fifth from right).

August

Maintenance break for the European XFEL



The Long Installation and Maintenance Period enabled major work on the European XFEL linear accelerator.

The European XFEL has undergone its first major maintenance shutdown since commissioning – the Long Installation and Maintenance Period – with its superconducting accelerator warmed from -271°C to room temperature after more than eight years of continuous operation. The shutdown enabled essential inspections and significant upgrades, including the installation of a new electron source and preparations for future enhancements. The facility is expected to resume user operation in spring 2026 with improved performance, marking an important step in its long-term development and continued role as a world-leading X-ray research infrastructure.

August

DESY welcomes 100 summer students from all over the world

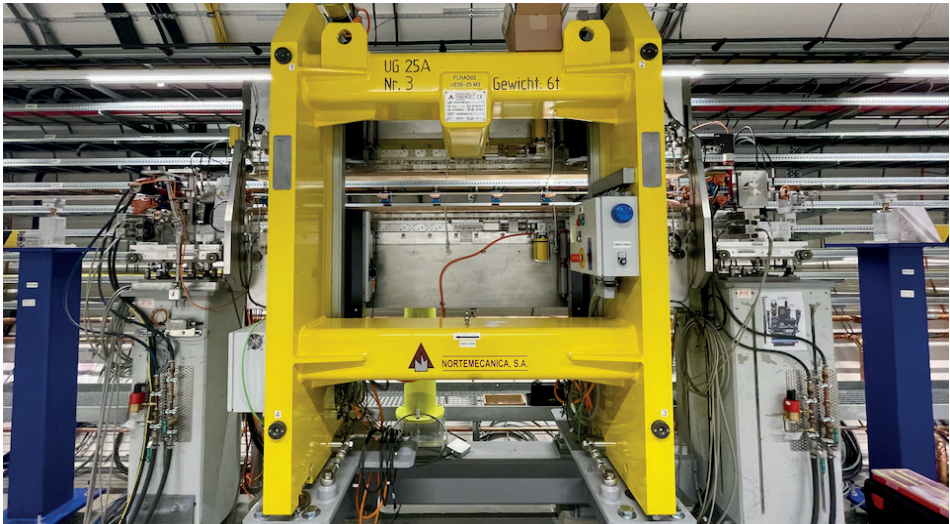
A total of 100 summer students from 33 different countries participated in DESY's summer student programme in Hamburg and Zeuthen this year. Students from Ukraine, Spain and Italy were particularly well represented among the participants. The students spent their time working on research projects, attending lectures, touring the campus and enjoying cultural exchange – and of course doing some sightseeing.



The 2025 summer students at the DESY campus in Hamburg (top) and Zeuthen (bottom)

FLASH restarts after extensive upgrade

Following a comprehensive 14-month upgrade of DESY's FLASH free-electron laser (FEL) facility from June 2024 to August 2025, the FLASH tunnel was closed again on 3 August to start commissioning the accelerator. The aim of the FLASH2020+ project was to offer new, unique capabilities for research on its FLASH1 FEL branch for users by making tailor-made, extremely stable and spectrally narrow X-ray pulses available for experiments. Combined with FLASH's high repetition rate, this opens up entirely new opportunities for precision studies in biology, chemistry and materials science, with exceptionally high temporal resolution in the femtosecond range.



New undulators open up novel scientific opportunities at FLASH.

DESY mourns the loss of Herwig Schopper

DESY and the physics community mourn the loss of a great scientist, science manager, diplomat and visionary. The physicist and former DESY and CERN Director General Herwig Schopper passed away in Hamburg on 19 August at the age of 101. He was Chairman of the DESY Board of Directors from 1973 to 1980. Herwig Schopper shaped the physics landscape in Germany and Europe like few others, guided by his vision of science without borders in the pursuit of understanding the fundamental workings of our world. In doing so, he also helped pave the way for DESY to become the international research centre it is today. DESY will make sure that his physics legacy lives on.



Herwig Schopper (1924–2025)

September

Rapid breakthrough: Superconducting cavity with attosecond precision

A DESY team achieved a major breakthrough by controlling a superconducting accelerator cavity with attosecond precision for the first time, reaching a timing accuracy of just 190 attoseconds. Reported in *Physical Review Accelerators and Beams*, the result significantly improves the stability of radio frequency fields used in free-electron lasers such as the European XFEL. Using an advanced “carrier suppression” technique, the researchers were able to measure and correct tiny fluctuations with unprecedented sensitivity, improving existing control systems by more than a factor of 10. This milestone enables more precise and reproducible ultrashort X-ray pulses, benefitting applications such as pump-probe experiments and opening up new possibilities for attosecond-scale science and advanced measurement technologies.



Precision squad: the team that controlled an accelerator cavity with attosecond accuracy

Hamburg state representation in Berlin with PETRA IV

DESY took the opportunity to present its flagship project PETRA IV to the public at the annual summer party hosted by the Hamburg State Representation in Berlin. This high-profile and widely attended networking event attracted around 2500 distinguished guests from the worlds of politics, business, the media, culture and science.



Hamburg's Mayor Peter Tschentscher (seventh from left) and State Councillor Liv Assmann (sixth from right) visited the DESY stand at the festival, here together with members of the DESY Board of Directors and employees.

European XFEL receives new electron source “Gun 5”

The performance of the European XFEL X-ray laser is set to be significantly enhanced with the installation of a new electron source, “Gun 5.2”, developed and tested at DESY's Photoinjector Test Facility in Zeuthen (PITZ). Delivered to Hamburg after years of preparation, the new system was installed during the European XFEL's Long Installation and Maintenance Period and represents a key upgrade to the accelerator's injector.

Electron sources, or “guns”, are crucial for generating dense electron bunches – the foundation for producing the XFEL's intense, ultrashort X-ray flashes. With its improved design, Gun 5.2 offers greater stability, reliability and flexibility, building on decades of expertise in superconducting accelerator technology. A major benefit for experiments is the extension of the high-frequency pulse by 30%, increasing the maximum number of X-ray →

September

→ flashes from 27 000 to 36 000 per second. This allows scientists to collect more data in less time and expands experimental possibilities. Overall, the upgrade strengthens the European XFEL’s role as a leading international research facility, enabling more precise studies of atomic and molecular processes.



The next-generation electron source in the European XFEL injector building

Hamburg's Finance Senator Dressel visits DESY

Andreas Dressel, Hamburg’s Senator for Finance, visited DESY to learn about the PETRA IV project and to discuss topics such as the close link between research and innovation for a city like Hamburg, particularly in light of developments surrounding the Science City Hamburg Bahrenfeld.



Hamburg’s Senator for Finance Andreas Dressel (left) gained further insights during a campus tour, here in the PETRA III experimental hall “Max von Laue”.

October

Topping-out ceremony for CAST building

On 8 October, the topping-out ceremony was held for the CAST building, which is situated directly opposite the PETRA III experimental hall “Max von Laue”. With its seven storeys, it towers above many of the surrounding buildings and will become the new centre for accelerator research and technology development at DESY.



Topping-out ceremony for the CAST building

Andreas Maier wins 2025 Bjørn H. Wiik Prize

Andreas R. Maier was awarded the 2025 Bjørn H. Wiik Prize – DESY’s most prestigious scientific honour – for his world-leading achievements in the field of laser plasma acceleration. Since joining DESY in 2020 and being appointed Lead Scientist in 2022, Maier and his team have achieved internationally recognised breakthroughs and helped to advance this emerging technology towards practical applications, including its potential use in DESY’s future project PETRA IV. Maier, who is known for combining hands-on experimental work with strategic foresight, emphasises that “belief in feasibility is a prerequisite

The ceremony marks the completion of the building’s structural shell and represents a significant milestone in the construction. The new building on the DESY campus, with its perfect view over the Science City Hamburg Bahrenfeld, also underlines the importance of accelerators not only for DESY, but also for science and the city.

for realisation” – an attitude reflected in his impressive research achievements.



Andreas Maier

Hi-Acts remains on course for innovation

The Hi-Acts innovation platform is set to continue long-term after a successful evaluation by the Helmholtz Association. Originally launched in 2023, the initiative has proven highly effective in accelerating the transfer of accelerator-based technologies from research into industry and society. Founded by DESY together with partner centres such as Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Helmholtzzentrum für Schwerionenforschung (GSI), Helmholtz-Zentrum Berlin (HZB) and Hereon, Hi-Acts connects scientific expertise with industrial needs. The platform has already attracted more than 116 companies and research organisations, with over 200 experts collaborating on innovation projects in areas such as new materials, electronics, energy and medical technologies.



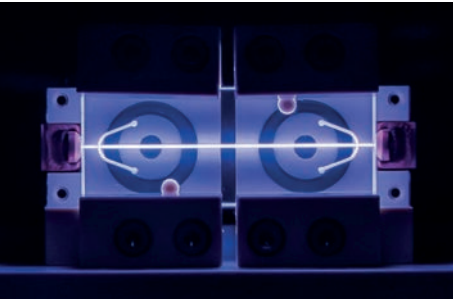
FLASH welcomes first user groups after shutdown

A new round of user experiments started at DESY’s FEL facility FLASH. During the extended FLASH2020+ upgrade, the FLASH1 FEL branch was completely replaced and converted into an externally seeded FEL, which was then gradually put into operation. The practically unchanged FLASH2 FEL branch had already resumed operation successfully. Just three weeks after the restart of the FLASH accelerator, FLASH2 achieved its usual excellent beam parameters.

November

Lenses made of plasma open up new ultrafast applications

Scientists from DESY and the Max Born Institute (MBI) in Berlin developed a novel plasma-based lens that can focus ultrashort attosecond light pulses without significant absorption or pulse stretching, a breakthrough for ultrafast experiments. By shaping plasma inside a tiny sapphire tube, the team created a tunable concave lens that focuses extreme-ultraviolet pulses more efficiently than conventional optics, enabling stronger light intensity and greater experimental precision. The innovation, described in *Nature Photonics*, promises to expand applications in ultrafast spectroscopy,



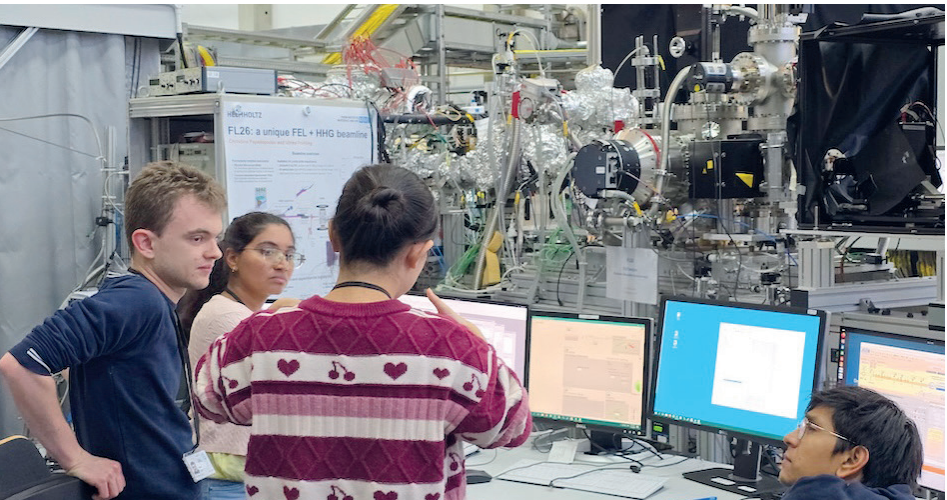
improve attosecond beamlines and support the next generation of attosecond light sources, demonstrating how plasma accelerator technologies can have far-reaching impacts beyond particle acceleration.

Ulrich Husemann takes over DESY’s Particle Physics Division

DESY has a new research Director in charge of Particle Physics: Ulrich Husemann, formerly professor at the Karlsruhe Institute of Technology (KIT), assumed the position in November. DESY is familiar territory for the particle physicist: Husemann worked on DESY experiments as a student, junior group leader and Physics Advisory Committee member.



Ulrich Husemann



Researchers from the Max Planck Institute for Nuclear Physics in Heidelberg were the first users at the upgraded FLASH facility.

DESY Day 2025 – Congratulations to all award winners!

On DESY Day on 5 November, the achievements of all DESY staff members were celebrated, with recognition given to exceptional dedication, outstanding ideas and developments as well as brilliant research work. As always, the focus was on science and innovative technologies, and newly appointed researchers were welcomed. The Jentschke Lecture was delivered by Sara Russell from the Natural History Museum in London and offered fascinating insights into astrobiology.



Prize winners, highlight speakers, newly appointed scientists and other contributors joined in celebrating DESY Day.



Ke Li

There were several reasons to celebrate in the Accelerator Division: Andreas Maier, Lead Scientist and head of the Plasma Acceleration and Lasers group, received the 2025 Bjørn H. Wiik Prize on DESY Day. Torsten Wohlenberg from the Accelerator Vacuum group was awarded a DESY Award for Exceptional Achievements in the field of engineering and technology for his outstanding contributions to the technical development and implementation of high-precision vacuum components and structural elements for beam manipulation at the European XFEL.

The Association of the Friends and Sponsors of DESY (VFFD) presented this year's PhD thesis award in equal parts to Ke Li (who joined the ceremony via video link from New Zealand) for her groundbreaking work on



Andreas Maier (left) with laudatory speaker Jörg Rossbach

mixed-reality interfaces for the operation of complex accelerator facilities, which she conducted as part of the Data Science in Hamburg Helmholtz Graduate School (DASHH), and to Benoît Richard for his new methods of molecular imaging using data from the European XFEL.

Patrick Rauer from DESY's XFEL Accelerator Operation group presented the scientific highlights of the development and demonstration of a cavity-based X-ray FEL (CBXFEL), from concept to reality.



Torsten Wohlenberg



Patrick Rauer

DESY scientists receive prestigious ERC Synergy Grants

Scientists from DESY were awarded highly competitive European Research Council (ERC) Synergy Grants for two ambitious research programmes. These grants are among the most prestigious offered in the European Union, recognising outstanding scientific excellence and unique collaboration.

DESY scientists Andreas Maier of the Accelerator Division and Jenny List of the Particle Physics Division, together with collaborators from CEA Saclay in France and the University of Rochester in the USA, secured nearly 14 million euros for the project NP-QED (Probing the non-perturbative regime of Quantum Electrodynamics with extreme light), of which 5.3 million euros will go to DESY. The project aims to use a plasma particle accelerator and a high-intensity laser to produce conditions close to the Schwinger limit, a physical limit where the constituents of the vacuum begin to separate. Under the theory of quantum electrodynamics (QED), in a vacuum, particles and antiparticles constantly emerge and annihilate each other spontaneously and near instantaneously. To achieve such conditions, the team will combine plasma accelerators with

high-intensity lasers, developing a dedicated experimental setup that includes a new detector and advanced plasma-based technologies. Beyond exploring fundamental physics, NP-QED will benchmark the maturity of plasma accelerators and evaluate their potential for future particle collider applications. The project brings together leading international partners,

including CEA Saclay, the University of Rochester, ELI-NP in Romania, and the Weizmann Institute in Israel.

The second project, comprising the DESY scientists Saša Bajt, Francesca Calegari, Henry Chapman and Nina Rohringer, was awarded 14 million euros for DESY and will combine atomic-scale imaging with attosecond science.



The NP-QED team (from left): Andreas Maier and Jenny List (both DESY), Henri Vincenti (CEA) and Antonino Di Piazza (University of Rochester)

25th anniversary of TTF – today known as FLASH

DESY celebrated a remarkable milestone in 2025: the 25th anniversary of the first lasing at the TESLA Test

Facility (TTF) – today known as FLASH, the first X-ray FEL in the world. This breakthrough laid the foundation for

the worldwide development of outstanding FEL user facilities. To mark this pioneering achievement, more than 200 scientists from across the world gathered on 17–18 November for a symposium at the place where it all began, on the DESY campus in Hamburg. The participants came together to reflect on FLASH's history, explore its contributions to current research and discuss the facility's ambitious future. The programme also featured a dedicated PhD session, along with ample opportunities to meet and reconnect with colleagues and collaborators.

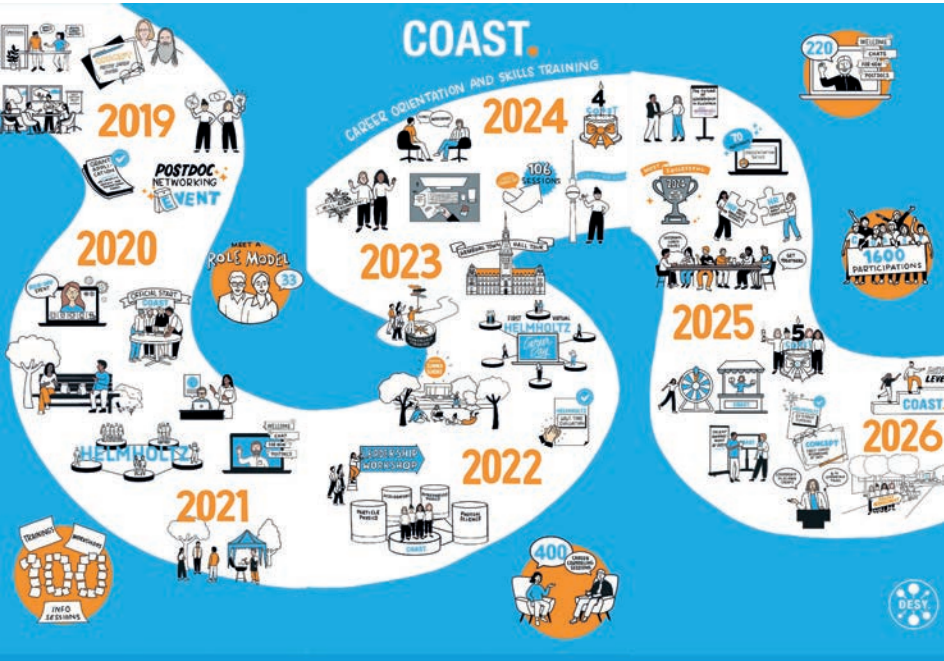


Participants of the symposium celebrating the 25th anniversary of TTF – now called FLASH.

November

COAST celebrates: Career development for early career researchers

On 12 November, the COAST career centre for postdocs celebrated its fifth anniversary with the conference “Career Development for Early Career Researchers – Best Practices and New Horizons”. Following funding from the Helmholtz Impulse and Networking Fund, COAST will continue as a permanent institution from 2026 on, financed from DESY’s own funds and the participation of the scientific divisions. Since 2020, COAST has organised around 100 training courses and 33 role model events, conducted 400 individual career consultations and set up numerous networking events and four virtual Career Days that focused on diverse non-academic career paths in collaboration with other Helmholtz centres.



DESY marks Orange Day against violence

On 25 November, DESY joined the International Day for the Elimination of Violence against Women and Girls by “turning orange” in a strong show of solidarity. Employees wore orange clothing and took part in events organised by the women’s representatives, including self-defence workshops, highlighting both awareness and empowerment in the fight against gender-based violence.



Self-defence training for Orange Day

December

DESY publishes its second Sustainability Report



DESY released its second Sustainability Report (2022–2024), highlighting progress in embedding sustainability across its research activities, with a strong focus on large-scale facilities and the flagship project PETRA IV.

Fusion alliance advances future energy research

Representatives from several German federal states, together with DESY and European XFEL, outlined next steps in advancing fusion research, aiming to develop the world’s first commercial fusion power plant in Germany. By combining expertise in laser and accelerator technologies, the partners aim to accelerate progress toward a climate-neutral energy source.



From left: Thomas Feurer (European XFEL), Dorit Stenke (Schleswig-Holstein’s Science Minister), Maryam Blumenthal (Hamburg’s Senator for Science) and Beate Heinemann (DESY) representing Germany’s north as a hub for fusion-related research



Patrick Rauer

2025 KFS Early Career Photon Science Award for Patrick Rauer

On 4 December, Patrick Rauer from DESY’s XFEL Accelerator Operation group was awarded the 2025 KFS Early Career Photon Science Award of the German Committee Research with Synchrotron Radiation (KFS) for his outstanding achievements in the further development of X-ray FEL sources, in particular the realisation of a cavity-based X-ray FEL (CBXFEL).

Cold, colder, European XFEL

Following a six-month maintenance and upgrade period, the European XFEL was cooled down again to its operating temperature of -271 °C. The work carried out during the shutdown included the installation of a new electron source (“Gun 5”), boosting the number of X-ray flashes by 30% to up to 36 000 per second, along with extensive infrastructure improvements and the creation of new experimental capabilities, such as attosecond pulse generation. These upgrades ensure that the facility remains at the forefront of X-ray laser research, with operations expected to resume for users from around the world in spring 2026.



Kick-off workshop for HICAPE

The kick-off workshop for HICAPE – Hamburg International Centre for Accelerators, Photonics and Entrepreneurship took place on 5 December at DESY. The HICAPE initiative aims to establish Hamburg as a world-class hub for photonics and accelerator research by bringing together the

cutting-edge photonic and accelerator technologies, expertise and infrastructures available in the city. The objective is to attract the world’s most talented and innovative minds to Hamburg in order to address pressing societal challenges through technological advancements and innovation.



Participants of the HICAPE kick-off workshop

Kick-off meeting for EPACE

On 15–16 December, the kick-off meeting for the EPACE doctoral network brought together around 35 participants from all consortium countries – marking the first time the entire team met in one place. The event gathered the 15 selected PhD students, their supervisors and co-supervisors as well as the principal investigators who will be driving the programme forward. The meeting not only set the scientific and collaborative tone for the years ahead, it also sparked excitement and a strong sense of community among all participants.



Participants of the EPACE kick-off meeting

Cost-effective laser optics for PETRA IV

DESY researchers developed a simple, flexible laser optics setup for plasma accelerators, a key technology for DESY’s flagship project PETRA IV. Using standard compo-

nents in a novel way, it offers high precision and stability while reducing complexity and cost, helping make advanced accelerator technologies more accessible.

Keeping our facilities at the forefront

In 2025, the European XFEL (see p. 32) marked a major milestone by combining six months of highly successful accelerator operation – achieving key milestones such as the first lasing of the cavity-based X-ray FEL demonstrator (see p. 50) – with a long installation and maintenance period (LIMP) that enabled significant infrastructure upgrades to provide new capabilities (see p. 46). Building on its development since first operation in 2017, these achievements position the facility well for future enhancements.

Picture: Sergey Tomin, DESY

Accelerator operation and construction

> PETRA III	28
> FLASH	30
> European XFEL accelerator	32
> PITZ	34
> REGAE	36

PETRA III

Exceeding operational target parameters

DESY's synchrotron radiation facility PETRA III reached an availability above target of 98.4% in 2025. Thanks to the extremely low fault rate, a mean time between failures of more than 71 hours was achieved across 25 beamlines. Especially after the hurdles that had to be overcome last year, this achievement highlights the efforts made by the technical groups to deal with the ageing infrastructure while resources are limited.

New light for innovations: Beamline P25 commissioned

The beamline portfolio in the PETRA III experimental hall "Ada Yonath" (PXE) is now complete – commissioning of the last beamline, P25, began in November 2025. This beamline has been designed and funded in collaboration between the PETRA III Photon Science group and the DESY Innovation and Technology Transfer group. It is aimed at academic research and industrial applications for applied biomedical imaging, powder diffraction and innovation. During commissioning of the respective undulator, PU25, first light was sent onto a photon beam screen on 25 September (Fig. 1). The beam position was optimised in coordination with Beamline P24, which shares the same canted straight section. Finally, on 26 November, Beamline P25

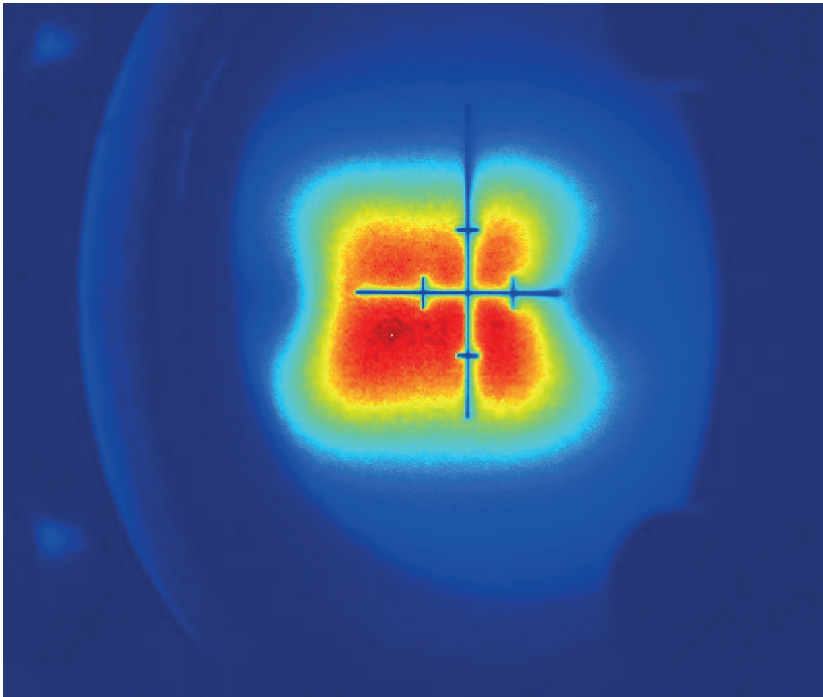


Figure 1
First light from the undulator PU25, recorded on the photon beam screen LM1 on 25 September 2025

passed the radiation safety check for standard beam operation.

Another slot is reserved for Beamline P63 in the PETRA III experimental hall "Paul Ewald" (PXN). This beamline is still in preparation and is expected to be commissioned in summer 2026.

Exchange of undulator PU02

The beam quality of Beamline P02 in the PETRA III experimental hall "Max von Laue" had degraded due to strong radiation damage to the undulator's permanent magnets. During the October 2025 service week, the entire undulator PU02 was replaced (Fig. 2). The old undulator was



Figure 2
Exchange of the radiation-damaged undulator PU02, located in the PETRA III experimental hall "Max von Laue", in October 2025

removed and the new one craned into position in less than three hours, including opening and closing of the tunnel roof in the experimental hall. As a result of the replacement, the beamline saw a doubling of the flux and an improved beam focus, which once again provide the desired high-quality experimental conditions.

Low fault rate enables high availability and MTBF

Regular user operation was scheduled between 4 March and 12 December 2025 with 4656 hours of beamtime, which were delivered with an availability of 98.4%. In total, only 63 faults with an average duration of 1.1 hours occurred during the user run, leading to a mean time between failures (MTBF) of 71 hours. The delivered 4584 hours of user run time were supplemented by 1117 hours of test run time. 54% of the user time was allocated to the 480-bunch mode and 46% to the 40-bunch mode. The alternative "low-beta optics" were in operation for 42 user run days.

The distribution of machine states in 2025 is shown in Fig. 3. The long-term development of the MTBF shown in Fig. 4 indicates that 2025 was the second-best operating year of PETRA III. Only in 2020 were the MTBF and availability better than in 2025. This is a great success, especially considering the ageing infrastructure of PETRA III.

The most impactful faults were caused by the cooling water system. Initially, a series of broken water hoses led to three water leaks during the user run within four weeks. In all cases, equivalent hoses at different sextupoles in the copper water circuit showed point-like holes, while the inner surface was covered with copper rust and crack defects. Due to the recurring fault pattern, all hoses of this type and in this location were exchanged during the summer shutdown. A series of samples were collected from other locations, but no problems were found.

Secondly, a broken water filter distributed small raisin-like particles throughout the copper water circuit around the accelerator ring. These particles clogged the 529 dirt traps in front of the magnet coils and power supplies connected to the same water circuit. All dirt traps had to be cleaned before operation could resume. As a consequence, dirt traps were installed directly on the inlet and outlet of all filters of this type in the PETRA complex.

Preparing for LPA injection tests

In February 2026, the laser plasma accelerator (LPA) LUX will be connected to the PETRA III injector complex. In a proof-of-principle experiment, the LPA will inject an electron beam directly into the DESY II booster synchrotron. From here, the goal is to transfer the LPA beam into PETRA III. The LPA beam will feature only very low

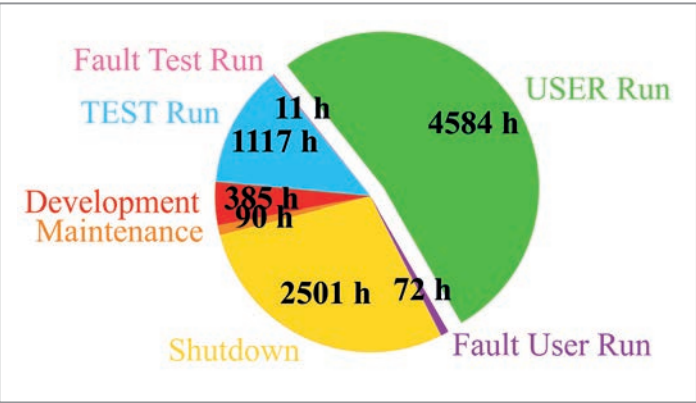


Figure 3
Time distribution of PETRA III machine states in 2025

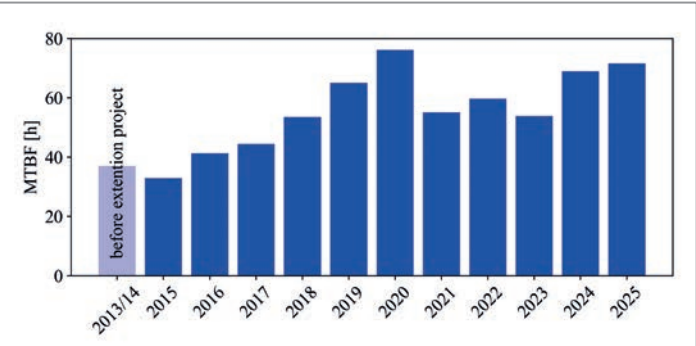


Figure 4
Long-time development of the MTBF during user runs

intensity, thus studies on the diagnostics resolution, especially for the beam position monitor electronics, with low-charge injection are ongoing. Furthermore, several adjustments in the timing system have to be implemented.

Injector refurbishment in 2026

From September 2026, the PETRA III complex will undergo an approximately six-month shutdown period. The duration of the shutdown is defined by the renovation of the LINAC II, DESY II and PETRA III radio frequency interlocks. Furthermore, the PIA accumulator ring will undergo significant refurbishment. As a consequence of the absorber faults of 2024 and a study with the wiggler beamline P61, which showed that only the light of the last five (of ten) damping wigglers in the straight section North reaches the beamline, it is planned to realign both the North and West wiggler sections during this shutdown. Moreover, in preparation for the PETRA IV construction activities, the magnet cables currently running through the "PR-Weg" (the old transfer line between PETRA II and the former HERA ring) will be rerouted.

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FLASH – back in operation

Transformation to a brighter and more flexible free-electron laser facility

FLASH, DESY's high-repetition-rate free-electron laser (FEL), has undergone a fundamental transformation as part of the FLASH2020+ project. With the upgrades of the linear accelerator and the complete renewal of the FLASH1 beamline, FLASH is now a highly flexible facility with two FEL beamlines comprising three radiation sources, as well as a third beamline for research and development, enabling the investigation and preparation of the next generation of accelerators. Following the completion of the FLASH1 installation in August 2025, the facility was brought back into operation in a very focused and highly systematic commissioning period. As a result, more than 1000 hours of beam-time could be made available to the user community in 2025, while at the same time further developing the capabilities of the new externally seeded FLASH1 beamline.

Successful upgrade to an externally seeded FEL in FLASH1

The FLASH facility has just celebrated its 25th anniversary since the first generation of self-amplified spontaneous emission (SASE) radiation and its 20th anniversary as a user facility. Since the early days, FLASH has been continuously upgraded and further developed, and it keeps setting benchmarks in the FEL landscape.

This year, with the replacement of the old FLASH1 FEL beamline, the major milestones of the facility's most recent upgrade programme, called FLASH2020+, were completed. As part of FLASH2020+, a large part of the facility was renewed, with the focus on the superconducting linear accelerator section during a nine-month shutdown in 2021–2022 and a complete renewal of the FLASH1 beamline



Figure 1
A glimpse into FLASH1 as seen from the beam dump looking upstream towards the photoinjector. Left: View of the tunnel after removal of the old beamline and after infrastructure refurbishment. Right: Newly installed FLASH1 beamline.

during a 14-month shutdown that ended on 3 August 2025. Figure 1 shows the tunnel after removal of the old FLASH1 FEL beamline, which was followed by installation the new FEL beamline.

The new FLASH1 beamline is now tailored to implement external seeding. In this concept, the properties of a laser beam are imprinted onto the electron beam using the high-gain or echo-enabled harmonic generation scheme. When these specifically prepared electron beams are passed through the undulators, the resulting photon beams inherit the stability in pulse energy and wavelength of the original laser. Additionally, these photon beams are close to being Fourier-limited, meaning that they have the smallest possible bandwidth for their pulse duration and are temporally coherent, which will allow for novel, phase-sensitive

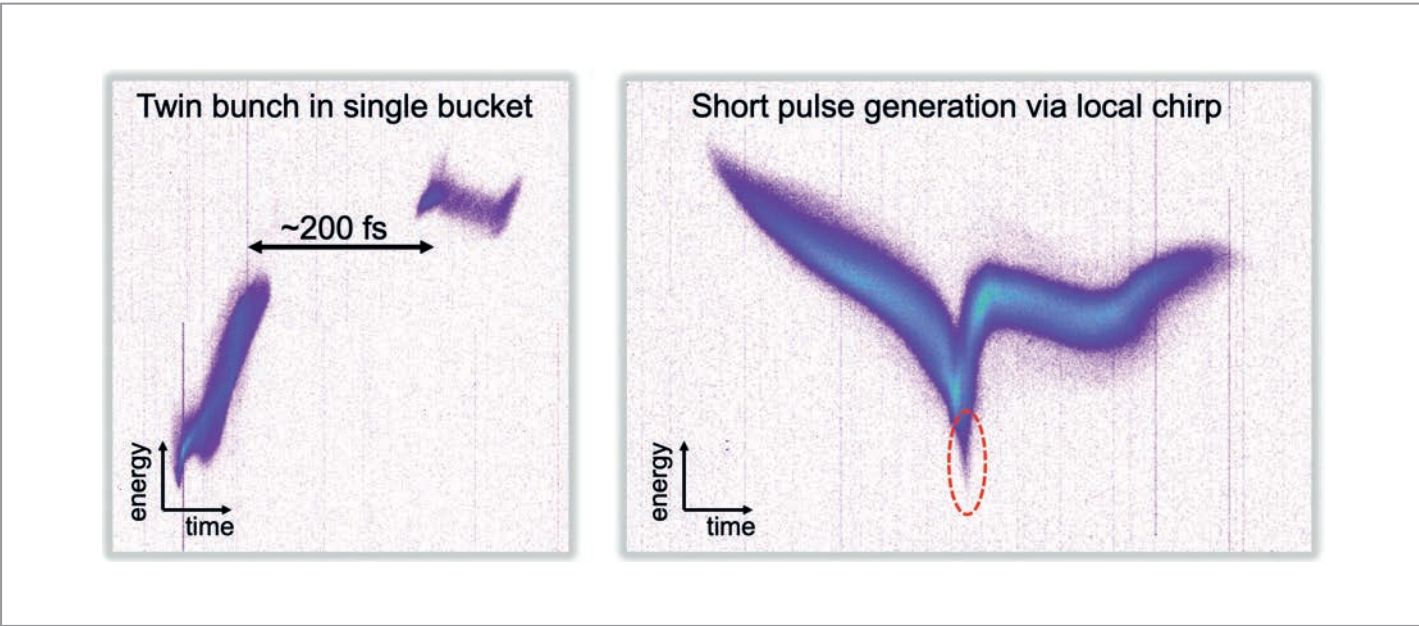


Figure 2
Examples of time- and energy-resolved electron beam profiles resulting from different R&D campaigns at FLASH. Left: Two electron bunches with variable delay and pulse compression were generated and transported in a single RF bucket. Right: Bunch with an extremely short (few femtoseconds) current feature, resulting from compression of a local chirp induced via laser heater in the FLARE experiment, at drastically increased time resolution. These tuneable short current spikes have also been demonstrated to lase, which manifests itself in a small feature extending downward from the current trace (circled in red for better visibility).

experiments. The installed undulators are of the APPLE-III type, which, on top of wavelength control, provides access to arbitrarily tuneable polarisation states by shifting the magnet arrays in the longitudinal direction. The undulator section has also been prepared for a small upgrade that will follow in April 2026. The implementation of two chicanes will enable new operation modes that will allow e.g. for more efficient generation of the shortest wavelengths.

The FLASH team is very grateful for the strong support of the DESY staff in the FLASH2020+ project and the renewal of the FLASH1 beamline. In particular, the tremendous efforts during the last shutdown weeks really made a difference and ensured that FLASH went back into operation on time.

Operation

On 4 August 2025, FLASH resumed operation, enabling a total of 3307 hours of planned operation until the end of the year. Of these 3307 hours, a total of 1646 hours were devoted to the recommissioning of the facility after the shutdown, 1056 hours to user experiments and 605 hours to research and development, FEL studies and preparation of user experiments.

Given the limited time available for commissioning, a highly strategic and systematic approach had been developed, which, in retrospect, proved successful, as all the initially set milestones were met. On the very first day, a beam was generated in the electron source (gun) section. After just one week, a first beam was sent to the FLASH2 beam

dump, as was required for conditioning of the superconducting radio frequency (RF) modules, which had been cooled down again at the end of the shutdown. After just three weeks, SASE operation in the FLASH2 beamline was re-established with high pulse energies and a nice transverse mode – a perfect start for further commissioning and subsequent user experiments.

Before beam delivery to users, 605 hours were spent on accelerator and FEL research (Fig. 2). During this time, among other achievements, the FLASHForward team prepared for next experiments on beam-driven plasma acceleration, and the experimental campaign FLASH Laser-Assisted Reshaping of Electron bunches (FLARE), an ErUM-Pro project at FLASH led by TU Dortmund University, demonstrated first lasing of femtosecond-level current spikes induced by special operation of the laser heater.

In parallel to user operation at FLASH2, commissioning efforts at FLASH1 were intensified. With continuous improvements of the electron and laser beam transport, optics and diagnostics, transverse overlap was demonstrated in November 2025. Longitudinal overlap was observed in December, followed by the first seeded lasing of FLASH1 at the fifth and sixth harmonic of the seed laser wavelength. For FLASH, this outstanding achievement marks an ideal conclusion to an extremely successful year 2025, which has opened the door to exploring further seeding regimes in 2026.

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European XFEL accelerator

A year split in half: versatile X-ray delivery for users followed by extended maintenance and installations

In 2025, the European XFEL accelerator complex – which is run by DESY – was operated for half a year with a great variety of X-ray delivery modes, before being switched off for an extensive facility maintenance and improvement programme. Nearly 4000 hours of accelerator operation were achieved, which included 2440 hours of X-ray delivery with an average availability of 95.1%, supporting a wide range of advanced free-electron laser (FEL) modes, such as self-seeding, attosecond pulses, two-colour operation and high-repetition-rate beams up to 4.5 MHz. The operational phase culminated in key milestones, including first lasing of the cavity-based X-ray free-electron laser (CBXFEL) demonstrator. The subsequent six-month maintenance period enabled major interventions, such as the first full cryogenic warm-up since 2016. In parallel, accelerator R&D advanced across multiple tiers, spanning near-term operational improvements, medium-term facility extensions and long-term developments in continuous-wave operation and advanced accelerator concepts and laying the groundwork for future upgrades of the European XFEL.

Operation summary

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 undulators to the beam dumps – was operated for almost 4000 hours in 2025, of which 2440 hours were spent on X-ray delivery to the experiments. The availability of the facility during X-ray delivery was 95.1%, averaged over all three FELs (Fig. 1).

The run concluded on 23 June 2025, initiating the long maintenance period. In preparation for the warm-up of the linear accelerator, all 784 superconducting cavities were mechanically detuned. The European XFEL cryogenic system was then safely warmed from 2 K to room temperature for the first time since 2016.

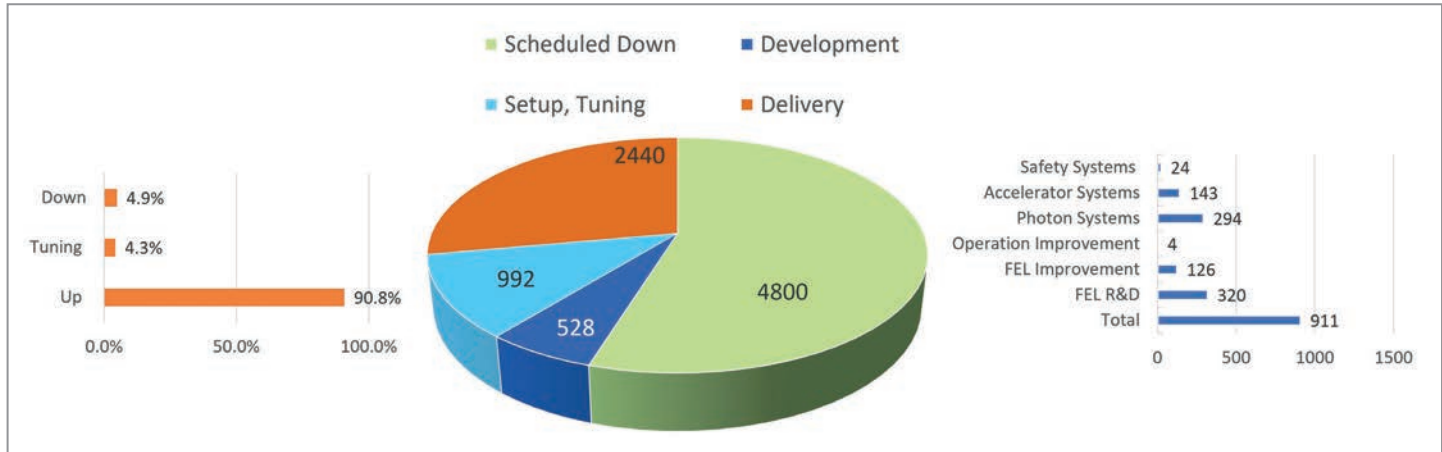


Figure 1
Centre: Distribution of yearly operating hours by category. Left: Availability during X-ray delivery in percent. Right: Distribution of development time in hours. Note that the total of development hours exceeds the scheduled operating hours, reflecting the parallel use of the facility for qualified activities.



Figure 2
After drilling its way through a 15 mm boron carbide absorber block, a 2.4 keV X-ray beam (coming from the left) creates a “plasma sword” in the ambient air behind the block.

a maximum electron beam power of 120 kW and the possibility to reach an average photon beam power of up to 100 W. Absorber tests were performed to validate assumptions that will eventually make it possible to increase the present safety limit and allow regular operation at high average power.

Generation and simultaneous lasing of bunches with a multiple of 720 ns distance were demonstrated using the new NEPAL injector lasers. Challenges with operating diagnostics, feedback systems and the laser heater still need to be resolved. The operation highlight of the year was the successful demonstration of first lasing of the CBXFEL demonstrator on 18 May in the last 30 minutes of a five-day-long commissioning campaign (see p. 50).

Research and development activities

The accelerator R&D programme addresses short- to long-term development needs for the European XFEL accelerator and photon sources. Grouped around different tiers, it supports the strategic goals of the facility.

The Improvement and Intelligent Process Control and Robotics tiers focus on near-term operational enhancements, with significant overlap with routine facility advancements. Key research includes attosecond pulse generation, twin-bunch dynamics, artificial intelligence (AI)-driven virtual diagnostics and mitigation of beam losses in small apertures.

The Extension tier targets medium-term upgrades to expand facility capabilities. Initiatives comprise accelerator-based THz radiation programmes – with PITZ advancing

towards a conceptual design report and the Superradiant THz Radiation Generation (STERN) project integrating a test chamber into the European XFEL beamline – alongside the successful CBXFEL demonstrator, which achieved first lasing in the SASE1 demonstration setup.

The Continuous-Wave (CW) Research tier establishes the technological basis for transitioning the accelerator to extended or continuous radio frequency duty cycles, centering on the development of high-performance cavities, modules and an all-metal superconducting injector. Recent advances include optimised heat treatment for single-cell cavities – now being scaled to nine-cell structures for a future CW module – while the construction of the injector test stand progresses. The multiple aspects of this work will be summarised in a Feature and Options Report, which will outline further R&D directions and provide important input for the decision-making process.

The Advanced Accelerator Concepts tier investigates plasma-based energy boosting. Using the NEPAL laser systems to test driver/witness bunch shaping under real conditions, the experimental validation of simulation models has been advanced. Development of plasma capillaries is another ingredient for a conceptual design report on the possible integration of such a device into the European XFEL.

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In 2025, the PITZ photoinjector test facility at DESY in Zeuthen was mainly operated with the goal to prepare the new electron source Gun 5.2 for installation in the European XFEL X-ray laser in autumn. Besides conditioning and characterisation of the gun, only limited beamtime was left for the other two research areas, THz free-electron laser (FEL) R&D and radiation biology. Despite the limitations, exciting results could however be obtained.

Gun 5 development and operation

Gun 5, the new generation of high-brightness electron sources, was designed to improve the operation of the FLASH and European XFEL user facilities. In January 2025, Gun 5.2 was taken into operation at PITZ after being preconditioned at DESY's Facility for L-band Conditioning (FALCO) in Hamburg in 2024. Further conditioning at PITZ was needed to reach the European XFEL target operation parameters, a cathode gradient of 60 MV/m and a radio frequency (RF) pulse length of 610 μ s. Gun 5.2 is the first electron source equipped with a symmetric RF coupler, which allows better symmetrisation of the accelerating field in the gun cavity. Its use enables an improved photocathode laser in-coupling, which was also successfully tested at PITZ. In September, the gun was dismantled from PITZ, transported to Hamburg and installed in the European XFEL injector. Operational tests and reconditioning started in mid-November. After the restart of the accelerator, the gun will drive the European XFEL for the next years.

With the installation of the new gun type, the provision of a hot spare became necessary. Gun 5.3 is foreseen as spare gun for the European XFEL, and it was set up in Zeuthen and preconditioned in Hamburg at FALCO from mid-July onwards. In September, the gun was sent to Zeuthen to exchange the RF distribution and install the gun at PITZ for further conditioning and beam characterisation. Its operation in the PITZ tunnel will start in the last weeks of 2025.

Production of three further guns continues in the DESY workshops in Zeuthen and Hamburg. Gun 5.4 will undergo

last brazing step in mid-December 2025 and will then be prepared for setup in 2026.

THz FEL R&D activities

After successful demonstration of a single-pass, high-gain 3 THz FEL using an LCLS-I undulator and high-charge electron beams from the PITZ photoinjector, a proposal was submitted to the European XFEL Management Board to consider the continuation of the THz R&D activities at PITZ. A three-year project was approved, starting in the third quarter of 2025, with different milestones defined for the whole duration. As part of the aim to demonstrate tuneability of the accelerator-based THz source, first 5 THz radiation was generated using a 19–20 ps (FWHM) flat-top laser. A Michelson interferometer was also commissioned on the diagnostic station to measure the THz spectrum.

Preparations for advanced diagnostics, i.e. the design of an electro-optic sampling (EOS) setup for measuring the temporal profile of the FEL pulse, have started. The goal is to achieve high-resolution, single-shot measurements using amplitude-encoded spectral interferometry with the existing PHAROS or NEPAL-P laser systems as probe sources. Preliminary modelling of the THz beam transport to the EOS station has been performed. Additionally, analytical calculations and simulations are carried out for the conceptual layout of an ideal machine that can serve as a THz source for pump-probe experiments at the European XFEL, using APPLE II-type (planar or helical) undulators covering a wavelength range from 10 μ m to 3 mm.

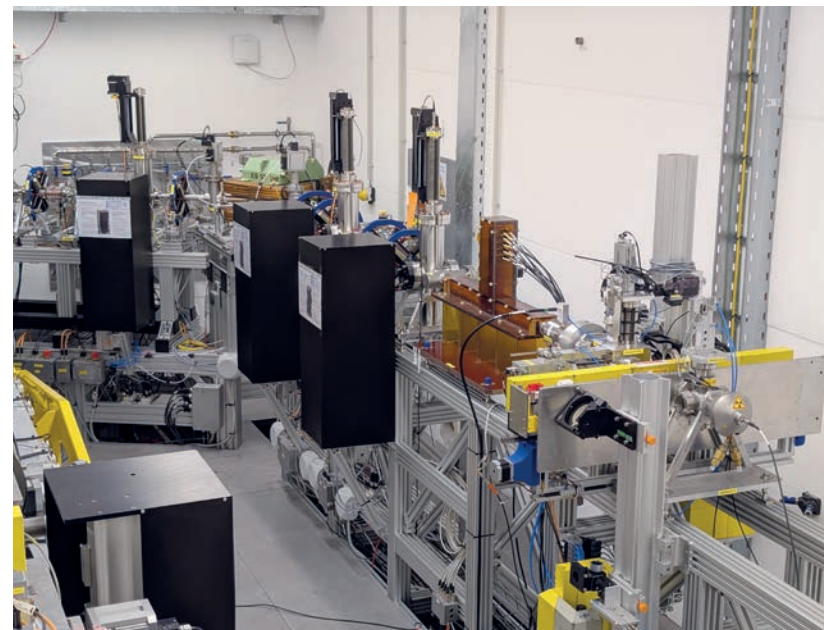


Figure 1

Left: New FLASH/ab beamline at PITZ. Right: Adult zebrafish (top) and zebrafish embryo five days post-fertilisation (bottom).



Radiation biology and dosimetry at FLASH/ab@PITZ

The radiation biology R&D platform FLASH/ab@PITZ enables *in vivo* preclinical systematic investigations of electron irradiation in a worldwide uniquely broad and tuneable parameter space, ranging from conventional (CONV) to ultrahigh dose rates (UHDR) of up to 10^{14} Gy/s. In 2025, the new FLASH/ab beamline (Fig. 1, left) was completed and taken into operation. Electron beam operation at an energy of 22 MeV was established over a wide charge range from ~ 10 pC to 3 nC. Dosimetry relied on gafchromic films, a flashDiamond detector, thermoluminescent dosimeters (TLDs) and an ionisation chamber, with alanine providing an independent, traceable dose reference for cross-calibration of TLDs and films. Ongoing studies aim to quantify possible dose rate effects in the film response. The availability of an X-ray generator in Zeuthen supported a standard reference for comparison with electron irradiation at PITZ.

The novel FLASH/ab beamline was employed for electron irradiation at dose rates of 0.04 Gy/s (CONV) and 10^5 – 10^6 Gy/s (UHDR) for radiobiological investigations. Studies with cancer and non-cancer cells revealed a pronounced UHDR-dependent oxidative sparing effect in non-cancer cells under 21% O₂ conditions. The establishment of standardised husbandry conditions for zebrafish, including breeding (Fig. 1, right), in 2025 made it possible to study radiobiological effects in normal tissue with zebrafish embryos. Preliminary results show that sparing of healthy tissue can be obtained by applying FLASH/UHDR irradiation with the PITZ beam, which is the main goal of the promising FLASH cancer radiotherapy.

To validate the FLASH conditions and demonstrate tumour control comparable to conventional irradiation while simultaneously reducing toxicity to normal tissue, translation to a mouse model is required. 3D-printed zoomorphic mouse phantoms were therefore fabricated and characterised via computed tomography (CT) imaging, showing close agreement with real mouse tissue. Initial irradiation experiments at the FLASH/ab beamline confirmed the suitability of those phantoms for preclinical dosimetry optimisation. In order to advance to more complex and more relevant cancer models that enhance the translational relevance of the research, *ex vivo* tissue experiments have begun in cooperation with the Max Delbrück Center for Molecular Medicine (MDC) in Berlin. The finalisation of the bio-laboratory has started, with the goal to house first mice in 2026.

Significant third-party funding has been acquired to support different projects in the areas of radiation biology and dosimetry, with a total amount of ~ 2 million euros, e.g. for the projects TRYSUB [1], ExVivoStrahl and NitroFLASH as well as new hardware.

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Reference:

[1] https://www.youtube.com/watch?v=FWvGX-JL_J0

3D structure determination with MeV electron diffraction at REGAE

3 GHz laser and plasmonic cathodes open up new opportunities for *operando* experiments

The first successful 3D atomic structure determination was achieved using MeV electron diffraction at DESY's REGAE facility, resolving the structure of the layered silicate muscovite – including hydrogen atoms previously only visible via complex neutron scattering – and the modulated structure of the quantum material tantalum disulfide. Using the facility's 1M Jungfrau detector and dynamical scattering refinements, the team demonstrated REGAE's capability to analyse light atoms and complex charge density waves. New record emittances were achieved with the newly implemented 3 GHz laser, while promising results with the operation of a plasmonic photocathode will enable even better control of the beam quality in future.

First successful 3D structure determination

Through continuous improvements of the beam quality and stability of REGAE, it is now possible to record diffraction data of such high quality that the atomic structure of samples can be determined without any prior knowledge.

For the reported experiments, extremely thin probes of the layered silicate muscovite with a thickness of 670 nm and of the quasi-2D quantum material tantalum disulfide (TaS_2) with a thickness of 30 nm were prepared and mounted on a specially developed sample holder. The measurements took place in the ultrahigh-vacuum experimental chamber of REGAE. In a first step, the samples needed to be very precisely positioned relative to the

electron beam by means of the REGAE on-axis microscope. While the samples were continuously illuminated with the pulsed electron beam, the angle of the sample surface relative to the beam direction was scanned over a range of 130 degrees with a resolution of 0.005 to 0.01 degrees in order to collect structural information about the probes from different directions. The diffraction images were recorded with the facility's 1M Jungfrau detector.

During the analysis of the data, structural refinements were applied according to dynamical scattering theory, enabling extremely precise data to be obtained from both materials. Particularly remarkable is the clear visibility of the hydrogen atoms in the mineral muscovite, which could

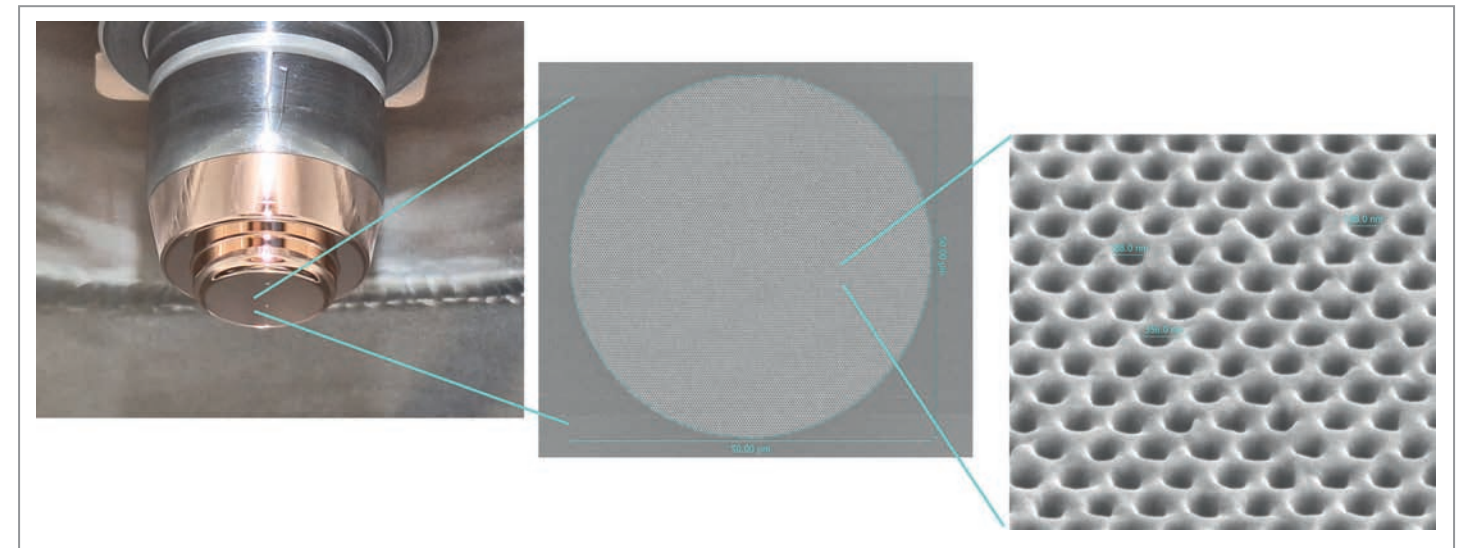


Figure 3

Single-crystal copper cathode head with nano-fabricated plasmonic patch. The patch has a diameter of 50 µm and consists of ~15 000 holes produced by means of a focused ion beam with nanometre precision in the DESY Nanolab.

previously only be seen in such detail with the aid of complex neutron scattering experiments (Fig. 1).

The extremely high quality of the data made it possible not only to determine the main structural reflection peaks of the quantum material TaS_2 , but also to include the much weaker signals of a charge density wave into the structural refinement. This enabled the team to also model the complex structure of this material with very high precision and to resolve small details (Fig. 2).

The results illustrate the great potential of REGAE for the investigation of battery materials, in which light atoms such as lithium play a major role. Thanks to the high penetration depths of electrons with energies in the MeV range, it will be possible in future to investigate not only isolated structures but also complete and functional components, such as batteries and transistors, as well as catalytic converters at work under *operando* conditions.

New record beam emittance achieved

After successful commissioning of REGAE's new 3 GHz laser, the ultraviolet intensity on the cathode could be significantly increased, so that a high charge of more than 150 pC per bunch train could be generated. After passing the beam through an aperture with a diameter of just 10 µm, a charge of only about 100 fC remained, but the beam emittance was reduced to a record value of ~150 pm, which is much lower than the ~20 nm typically achieved with the short-pulse laser at comparable charge. First experiments with this small-emittance beam demonstrated the expected increased coherence length also at reduced spot size at the sample position. MeV electron

diffraction can thus now be extended into the range of microbeams, enabling the structural analysis of micrometre-sized crystals, e.g. from biological materials.

The next level of beam quality control requires the investigation of new options for optimising the emission process at the cathode itself. For this purpose, the REGAE group has teamed up with a group working on the continuous-wave upgrade of the European XFEL X-ray laser. In order to design an electron source (gun) suitable for this project, plasmonic photocathodes are being investigated. The production of these cathodes is a challenging task in itself, as it requires the machining of a single-crystal copper base part with very high surface quality, into which a regular array of tiny holes is drilled using a focused ion beam (Fig. 3).

First tests with a plasmonic cathode in an operating radio frequency (RF) gun are now being performed at REGAE. While the measurements are still ongoing, a major step has already been reached. Even at gradients as high as 70 MV/m, no dark current generated by the plasmonic structure could be detected. This is not obvious, as geometrical structures in the cathode surface are prone to dark-current emission due to strong local field enhancements. Dark current from the gun causes many problems, such as background in diffraction images at REGAE or radiation problems in the European XFEL. This first result is thus a precondition for the use of plasmonic cathodes in accelerators.

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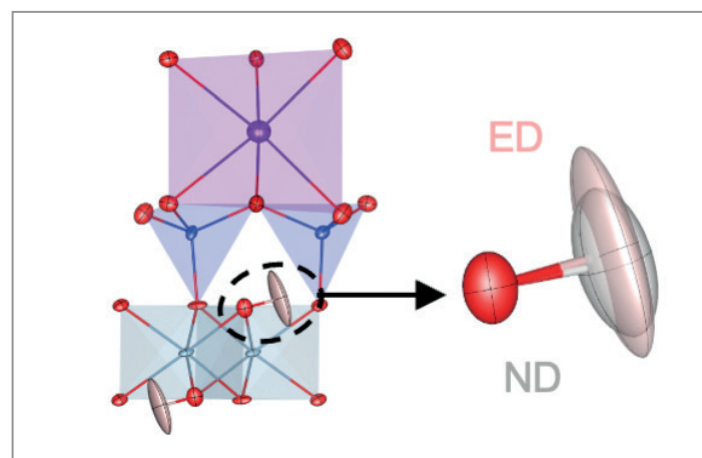


Figure 1

Left: Structure of the layered silicate muscovite obtained by means of electron diffraction (ED) at REGAE. For the hydrogen atom of the O-H group, anisotropic thermal displacement parameters were determined in analogy to neutron scattering results. Right: The neutron data (ND) are overlaid in grey.

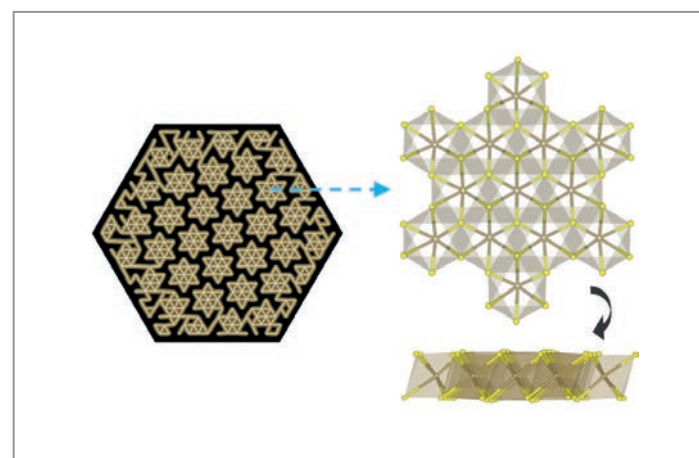


Figure 2

Left: Rendering of the modulated structure of $\alpha\text{-TaS}_2$ as obtained through MeV electron diffraction at REGAE. The structure is made up of star-shaped tantalum clusters. Right: A closer view of a single cluster shows 13 tantalum atoms together with the coordinating sulphur atoms.



Developing the technology for future facilities

The MAGMA plasma accelerator driven by DESY's flagship laser KALDERA: Electrons are accelerated on a few millimetres with 100 shots per second. This increased repetition rate paves the way for active stabilisation of the plasma accelerator's performance in the future, bringing it a big step closer to first applications (see p. 66).

Picture: Sören J alas, DESY

Highlights · New technology · Developments

➤ PETRA IV – the ultimate 4D X-ray microscope	40
➤ 40 years of DESY II beam operation	44
➤ Maintenance break for the European XFEL	46
➤ Doubling cryogenic safety valves at the European XFEL	48
➤ Lasing of a cavity-based X-ray FEL	50
➤ Flat-top laser pulse shaping at the European XFEL	52
➤ European XFEL superconducting undulator test stand	54
➤ SLASH – the FLASH seeding laser	56
➤ FLASH's new personnel interlock	58
➤ Electrons in focus at FLASHForward	60
➤ Active energy compression of laser plasma-accelerated electron beams	62
➤ Programmatic laser structuring	64
➤ KALDERA	66
➤ The SINBAD-ARES linear accelerator	68
➤ Attoseconds for accelerators	70
➤ The SHOGWAVE project	72

PETRA IV – the ultimate 4D X-ray microscope

PETRA IV is on the national prioritisation shortlist for large-scale scientific infrastructures

PETRA IV is the planned ultralow-emittance upgrade of the existing PETRA III storage ring. DESY's flagship project will be the brightest synchrotron light source in the world. Academic and industrial users will benefit from the enormous increase in coherent X-ray photon flux, new cutting-edge beamlines, novel experimental possibilities and the new business model in preparation for the facility. The accelerator complex is based on an ultralow-emittance 6 GeV storage ring, with a new booster injector complemented by a full-energy 6 GeV laser plasma injector. The accelerators and their subsystems are in an advanced state of design and prototyping that will allow a timely start of the project when approval will be received. PETRA IV is a cornerstone of the Science City Hamburg Bahrenfeld and will provide easy on-demand access, extended services and support for non-expert synchrotron radiation users, especially for the processing and analysis of their data.

Advancing PETRA IV: Preparation Project and continued prototyping programme

The PETRA IV Preparation Project started in January 2025 with 31 work packages. It aims to achieve readiness for execution of the PETRA IV project at the beginning of 2027. Key deliverables are to be accomplished in seven work package groups.

Planning for the civil construction programme began with the PETRA IV North-West area, including the new PETRA Experimental Hall West (PXW), which will accommodate 17 new beamline sectors (Fig. 1), as well as the new radio frequency (RF) Hall North, two supply buildings, all connecting tunnel sections and two laboratory and office buildings.

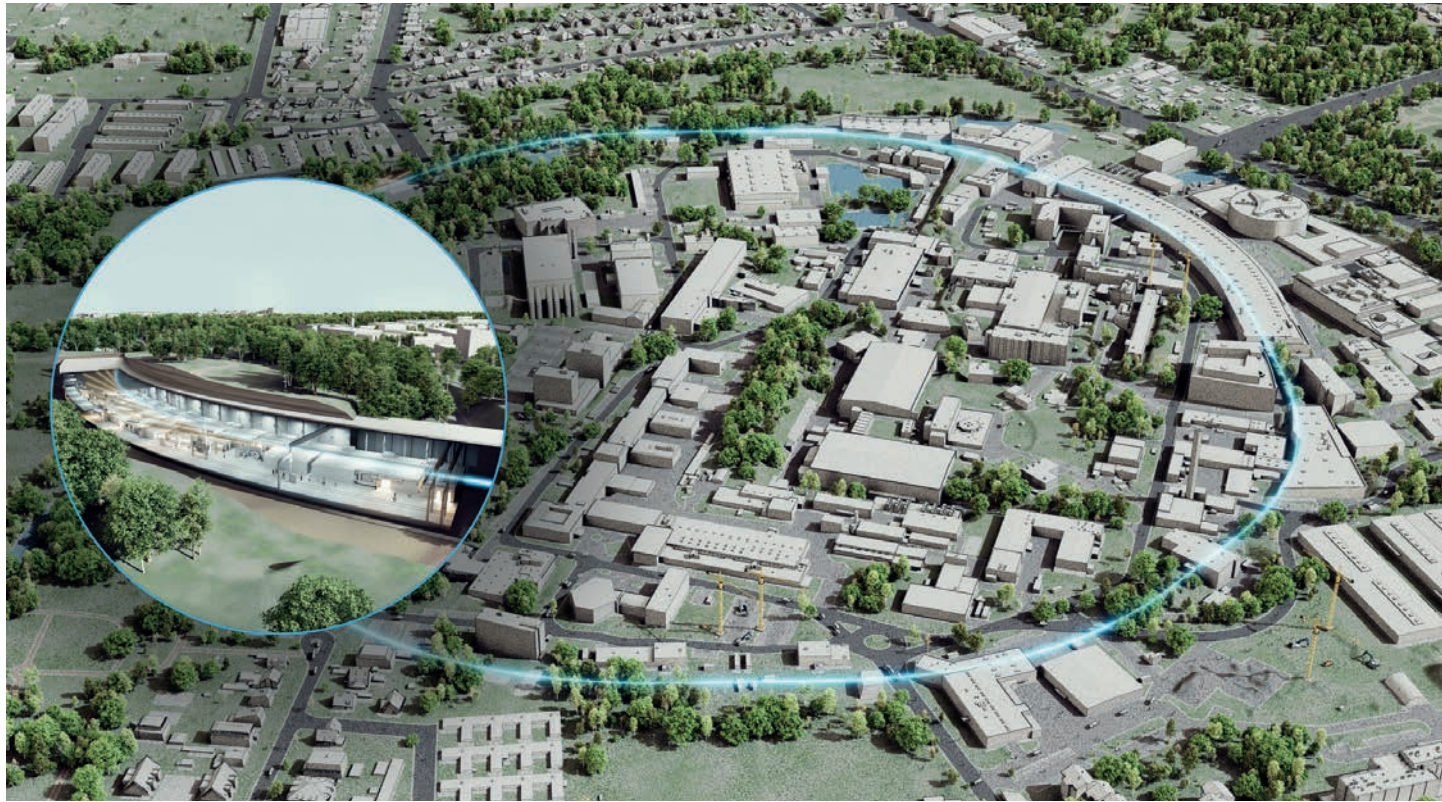


Figure 1
Artistic view of the planned DESY campus with PETRA IV. Inset: Zoom into the new PETRA Experimental Hall West (PXW).

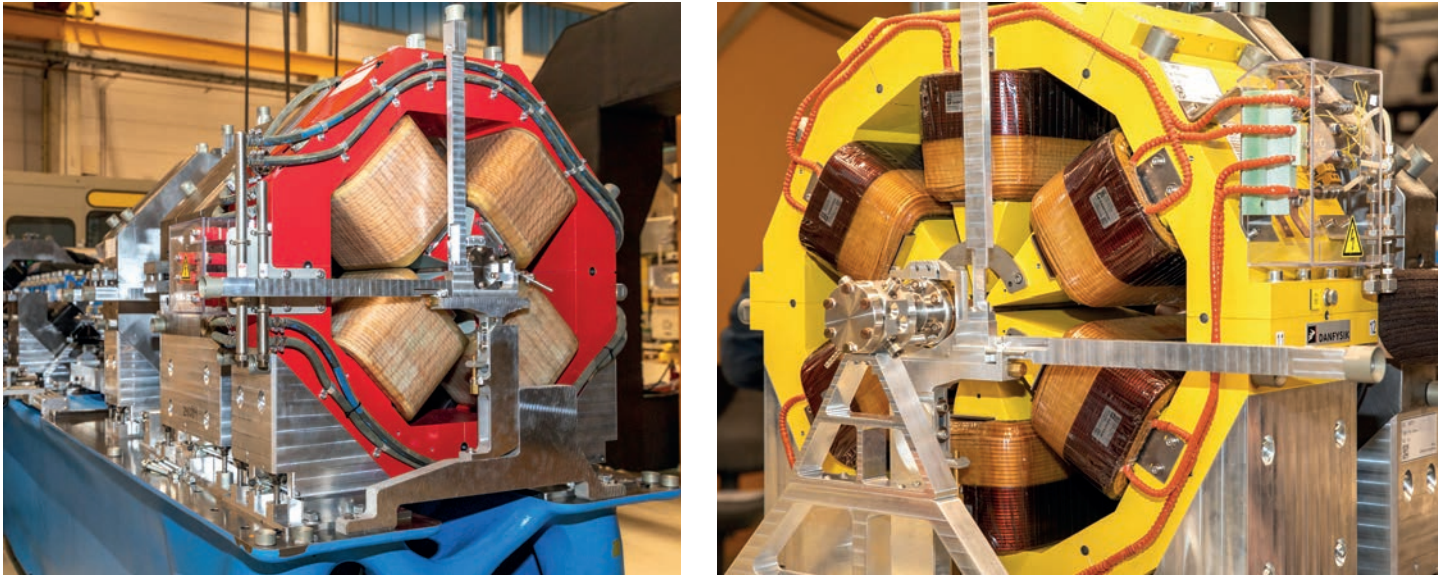


Figure 2
Left: Fully assembled demonstrator girder (blue) with magnets (red and yellow) for the PETRA IV storage ring. Right: Chamber for a beam position monitor in front of a sextupole (yellow).

The performance of the storage ring with a hybrid six-bend achromat (H6BA)-based lattice was tested under realistic error scenarios in all operating modes. With full coupling, PETRA IV will achieve an emittance of 12 pm-rad in both planes with perfectly round photon beams, putting it well ahead of all existing and planned fourth-generation light sources.

A key element of the prototype programme was the construction of one of the girders that make up the H6BA lattice cell. Four such girders per cell accommodate the sequence of magnetic, vacuum and diagnostics elements, and they are all individually optimised for the corresponding weight load. The demonstrator of the first girder type in the H6BA cell was completed (Fig. 2).

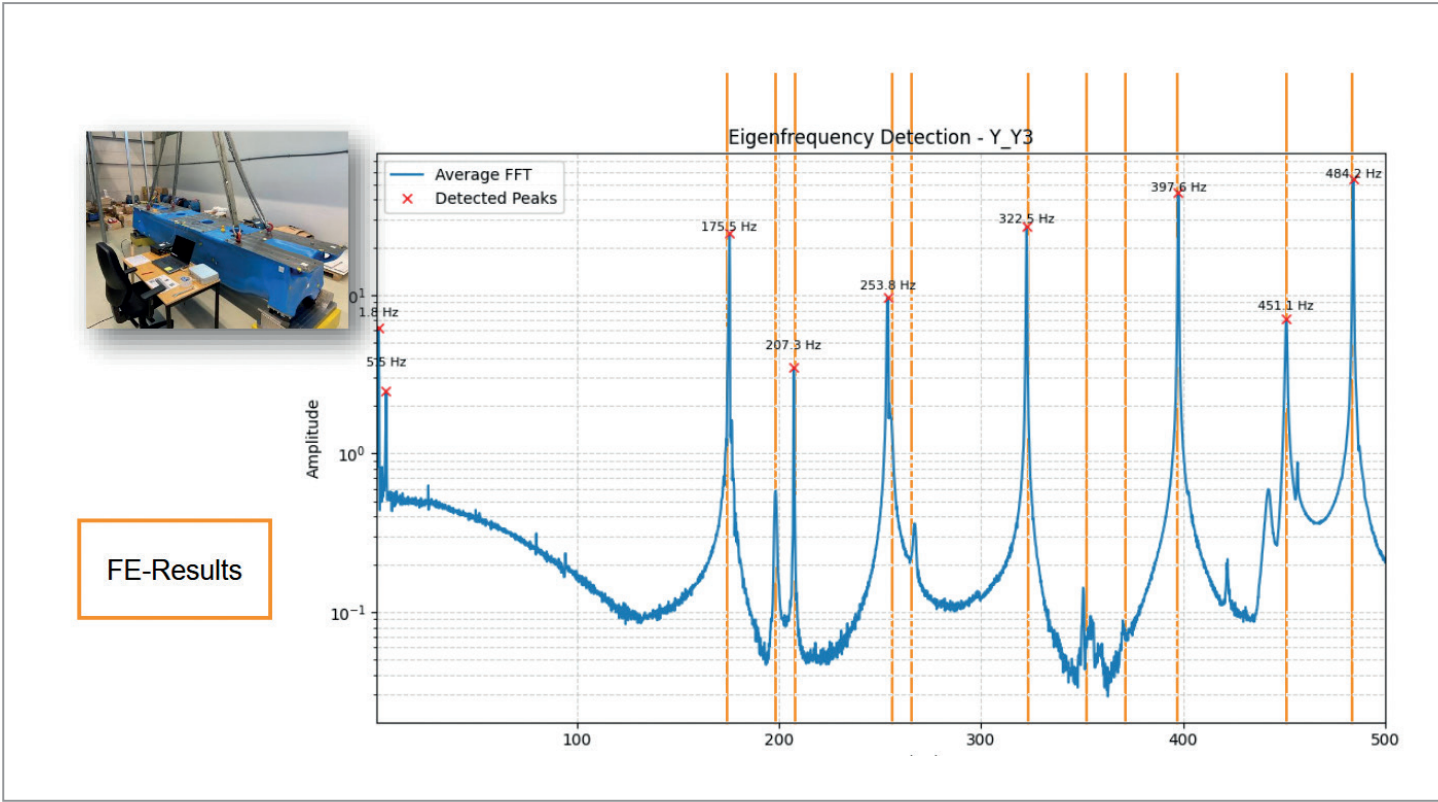


Figure 3
Vibration measurements of the girder eigenfrequency spectrum (blue) compared to ANSYS simulations (orange lines)

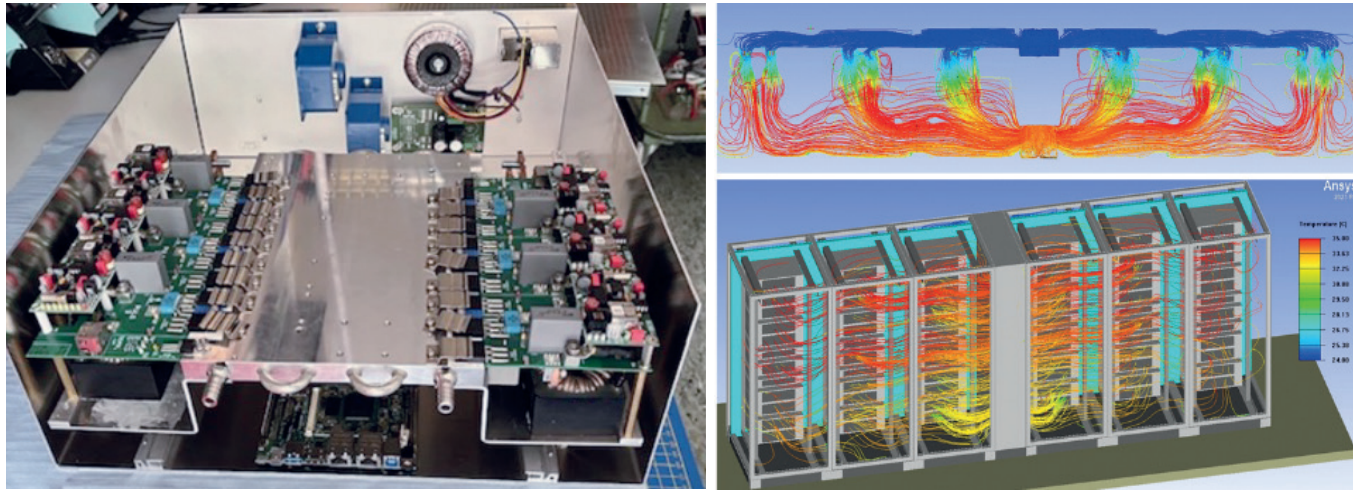


Figure 4
Left: First mechanical design studies for high-current magnet power supplies. Right: Simulation of the air flow within water-cooled racks to optimise the cooling power and minimise the required energy consumption.

An extensive series of tests were carried out to assess and improve the assembly and alignment procedures and to test the response of the girder to external vibrations. Agreement between the expected resonant frequencies and the measured ones is excellent, as shown in Fig. 3.

The prototype programme allowed progress to be made with the design of the beam position monitor system, the first prototype electronics for the feedback system as well as the x3timer board for the distribution of the synchronisation signal, which are being tested for functionality. Alternative designs, such as a Shintake-type cavity, are being studied for the 1.5 GHz RF cavities.

Figure 4 shows the mechanical design of the future high-current 200 A magnet power supplies (left panel). Water-cooled racks were selected to maintain optimal operating conditions for these power supplies. The air flow and the corresponding temperature distribution have been simulated to provide maximum cooling power with minimum electricity consumption for the entire water-cooling system (right panels).

The prototype programme for a novel injector based on laser plasma acceleration (LPA) – the PETRA IV Plasma Injector, PIP^{IV}) – was expanded. The existing LUX facility was reversed in the same tunnel to be able to inject 300 MeV electron bunches into the DESY II booster synchrotron. The goal is to demonstrate the feasibility of an LPA injector for user operation starting in March 2026. The layout of the full-energy 6 GeV plasma injector has been optimised, and a new injection point in the H6BA lattice has been identified, significantly lessening disruption to the adjacent infrastructure (Fig. 5).

As part of the PETRA IV Preparation Project, the conceptual design of the new undulators and frontends is progressing as well towards the goal of delivering photon beams with a brightness increased by a factor of 500 to 1000 in the hard X-ray range, underpinned by the ultralow-emittance lattice. Full exploitation of the source potential is complemented by the transformation of the user model – initially for the PETRA III storage ring and later for PETRA IV – from a call-based beamtime proposal system (with two calls per year) to a rolling-access proposal scheme with the possibility to submit proposals for comprehensive projects, not only single beamtimes. The new access scheme is currently being tested at five beamlines at PETRA III to gain experience with the new approach. First results are promising, and the new access scheme will be scientifically reviewed in March 2026 after the first pilot phase of two years.

Transformation is a goal not only for the accelerator technology, business model and user operation, but also for administrative processes, e.g. digitising procurement and recruitment processes, digitising and harmonising safety assessments for components and trades and improving digital forms in general. A key element for this transformation of digital processes is the application of artificial intelligence to the workflow to further improve the user experience in digitised processes.

PETRA IV selected as a large-scale scientific infrastructure of national importance

In 2024, the German federal government issued a call for the submission of concepts for new large-scale scientific infrastructures. The PETRA IV project team successfully

submitted its short concept (“Kurzkonzept”) in October 2024, which was then evaluated by expert panels under the auspices of the German Science and Humanities Council (Deutscher Wissenschaftsrat, WR) in three different subcategories: scientific excellence, potential for innovation and technology transfer as well as costs and risks including sustainability.

On 8 July 2025, Dorothee Bär, Minister at the Federal Ministry of Research, Technology and Space (BMFTR), announced the successful projects, among them PETRA IV, which was selected as one of nine large-scale scientific infrastructures of national importance.

Engineering Design Report completed

Subsequently, the German Science and Humanities Council was charged by the BMFTR to review all prioritised projects in preparation for a decision for funding. The review includes an update of the existing material provided with the short concept as well as the submission of a comprehensive project description collected in the PETRA IV Engineering Design Report (EDR). The EDR version for the evaluation was completed in November 2025 and will be finalised for publication in spring 2026, describing the status of the project at the end of 2025.

On-site evaluation by the German Science and Humanities Council

The evaluation of the PETRA IV project by the review panel of the German Science and Humanities Council took place on 2–3 December 2025. In dedicated sessions with representatives of the user community, DESY’s

Foundation Council and the PETRA IV project team, as well as the DESY management including the Board of Directors, the status and scope of the project were reviewed in detail. The evaluation also included a guided tour of experimental stations in the PETRA III experimental hall “Max von Laue”, the new LPA prototype injector system for DESY II, the PETRA IV prototype programme, a number of representative science institutions and the innovation and start-up ecosystem on the DESY campus, DESY’s computing centre and an information point on the various construction projects on campus. The tour demonstrated the enthusiasm and dedication of the project team and DESY staff, which was also reflected in the concluding remarks of the evaluation panel at the end of the visit.

Following completion of the project review, the results are expected to be announced in 2026. In the meantime, the project team continues to prepare all necessary steps for possible project execution starting in 2027.

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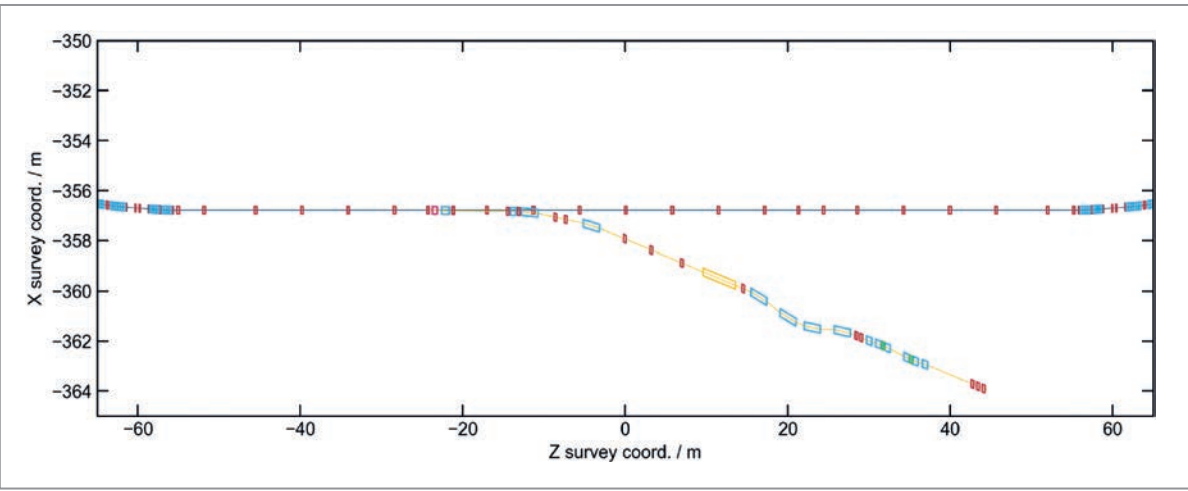


Figure 5
Location of the PETRA IV LPA injector at the southern straight section of the PETRA IV ring

40 years of DESY II beam operation

Pre-accelerator for PETRA III and test beam facility

On 22 March 2025, the DESY II synchrotron celebrated 40 years of beam operation. For decades, DESY II has been the central machine in DESY's accelerator complex, delivering electrons and positrons for the storage rings DORIS, PETRA and HERA as well as the Test Beam Facility. Today, DESY II serves as a pre-accelerator (booster) for the PETRA III storage ring and supplies electrons for operation with high reliability and stability, generally achieving an availability of over 99%. In addition, the DESY II Test Beam Facility provides test beams to nearly 450 users from a wide range of countries every year, making it an indispensable infrastructure for the international particle physics and nuclear physics community.

Facilities in the DESY ring tunnel

DESY's first accelerator, DESY I, began beam operation in 1964. It initially served as a synchrotron for particle physics experiments, before being used as a pre-accelerator for the larger storage rings DORIS and PETRA. In view of the HERA electron-proton collider project with its need for acceleration of both protons and electrons, the construction of a new electron synchrotron booster, DESY II, was approved in May 1983.

The design, construction and commissioning of the new accelerator were finished in less than two years. Within a four-month winter shutdown from November 1984 to February 1985, DESY II was fully installed in the ring tunnel (Fig. 1). The first electron beam from the LINAC I pre-accelerator was injected into DESY II on 22 March 1985. Initial

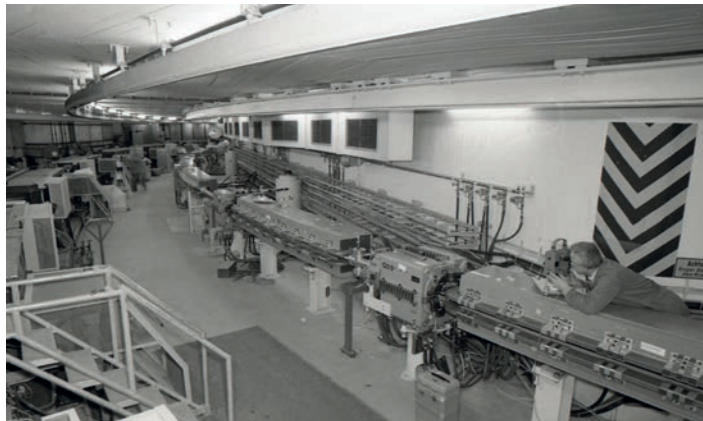


Figure 1
The DESY ring tunnel in 1985 during the alignment campaign of DESY II. DESY I is visible on the left on the "Ringträger" support structure.

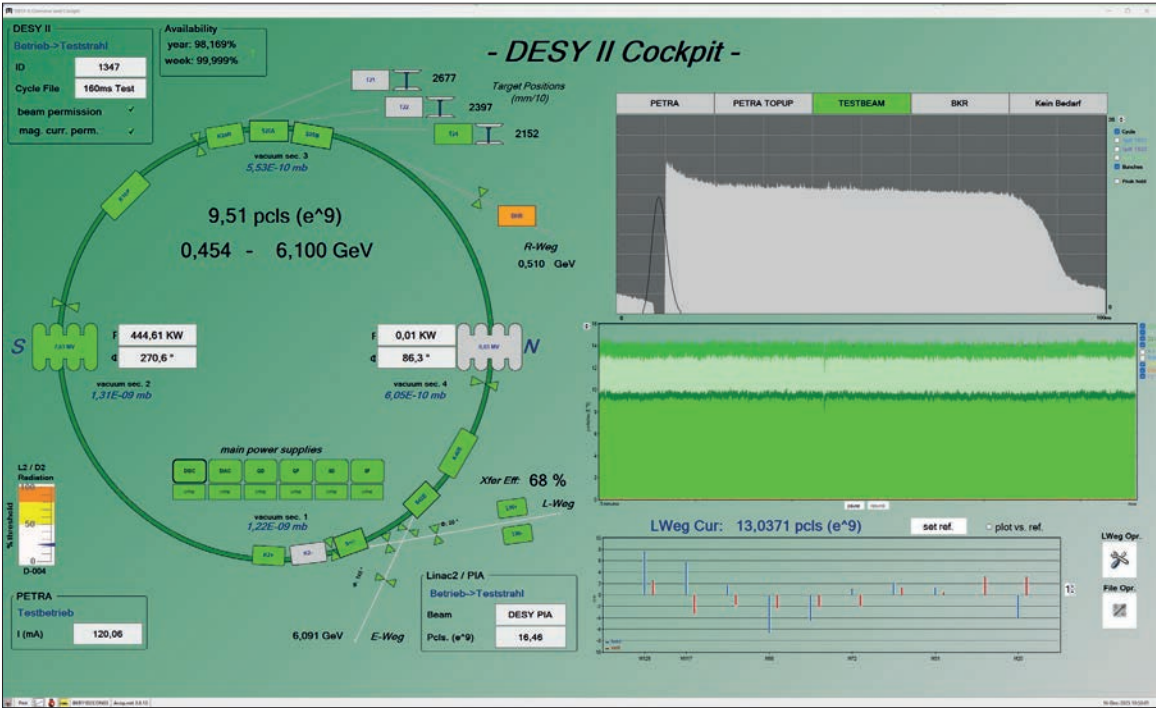
tests were conducted in parallel with normal operation of the old 7 GeV synchrotron DESY I. After completion of the PETRA collider programme in 1986, DESY I was converted into the proton synchrotron DESY III to supply protons for the HERA collider. After HERA operation ended in 2007, DESY III was shut down and gradually decommissioned. Since then, DESY II has been the sole facility operating in the ring tunnel.

DESY II is an electron and positron synchrotron with a circumference of 292.8 metres and a fixed magnetic-current or beam energy cycle of 12.5 Hz (Fig. 2). Injection usually takes place at an energy of 450 MeV. Within half a cycle period, i.e. in 40 ms, the beam is accelerated along a sinusoidal energy curve and extracted at the defined time.



Figure 2
Injection and extraction area of DESY II in 2025

Figure 3
Overview of operation with charge measurements in the transfer lines and DESY II as well as status overview of radio frequency (RF) parameters, kicker magnets, power supplies and test beam operation



As a pre-accelerator (booster) for PETRA III, DESY II achieves an extraction energy of 6 GeV and thus plays a major role in the pre-accelerator chain of the synchrotron light source. DESY II also houses the Test Beam Facility, which has three beamlines and enables a wide range of experiments for particle physics and nuclear physics.

Electrons for PETRA III operation

Most of the DESY II operating time is used to accelerate electron bunches to 6 GeV and send them to PETRA III, where they are used to fill the storage ring or keep the current constant (top-up operation mode). As a consequence, DESY II must deliver beam to PETRA III every few minutes, depending on the filling scheme. This requires high reliability and operational stability, with an availability beyond 99% usually being reached.

After four decades of operation, DESY II remains a key enabler for PETRA III, combining automation, robustness and reliability at a level that is essential for continuous top-up operation. Operation is fully automated without the need for manual intervention by the operators. The beam requests from the different users (PETRA III or test beams) directly set the parameters required for the accelerator (Fig. 3).

DESY II Test Beam Facility

A dedicated Test Beam Facility with three independent beamlines was installed in Experimental Hall 2 at the end of the 1980s. The electrons are generated by hitting a thin carbon-fibre target that is inserted in the DESY II primary

beam, generating bremsstrahlung photons. These photons are converted into electron-positron pairs by means of a secondary target (a thin copper plate). A dipole magnet is then used to select the particle type and momentum for the test beam. In 2006, major upgrades were installed, including first beam telescopes, reference detectors to measure the position and arrival time of the individual beam particles with high precision, and a 1 T superconducting solenoid.

Users at the DESY II Test Beam Facility have performed detector systems research and development for a wide range of experiments, including HERA, the planned TESLA – later International Linear Collider (ILC) – accelerator, the Large Hadron Collider (LHC) and the High-Luminosity LHC (HL-LHC). With close to 450 users from 24 countries (in 2025), the Test Beam Facility is therefore an essential infrastructure for the international particle physics and nuclear physics community. Since 2019, it has been one of the facilities hosting the highly successful "Beamline for Schools" physics competition, in which teams of high school students can propose experiments to be conducted at the test beamlines at CERN and DESY.

Outlook

For DESY's future project PETRA IV, it is foreseen to upgrade the injector chain with a new, state-of-the-art booster synchrotron, DESY IV. In this context, it is currently planned to remove DESY II, and the ring tunnel will have to undergo a complete infrastructure overhaul.

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Maintenance break for the European XFEL

Long installation and maintenance period 2025

Construction of the European XFEL began in early 2009. Eight years later, in May 2017, the first X-ray laser light reached the experimental hall in Schenefeld, and in September 2017, the facility officially entered operation. The year 2025 marks another important milestone for the European XFEL accelerator: During the long installation and maintenance period (LIMP), extensive maintenance tasks and significant upgrades to the facility infrastructure were carried out, and new and enhanced capabilities were introduced across the facility.

2025 facility maintenance

To ensure safe and reliable facility operation, regular maintenance is required. In eight years of operation of the European XFEL facility, a typical maintenance pattern had



Figure 1
Top: Two-valve configuration in the main accelerator tunnel (lower left corner) with complex vessel piping. Bottom: Cryogenic feedbox in the injector building.

been established: two weeks in summer and a somewhat longer maintenance period in winter due to the Christmas holidays. The maintenance period in 2025 differed significantly from all the previous years, however. Starting on 23 June 2025, it was extended to more than seven months, lasting until 26 January 2026. The duration of this long installation and maintenance period was determined by the need to re-certify and upgrade the safety valves of the cryogenic system. In addition, this longer time period was used to perform other invasive maintenance tasks on import technical infrastructures.

Upgrade of the cryogenic system

The cryogenic system must ensure both machine and personnel safety, particularly in the event of a sudden helium evaporation. Safety valves are essential for this purpose. In accordance with the Pressure Equipment Directive, these valves must be inspected every five years. The original single-valve design required a full warm-up of all accelerator modules for testing. To avoid this lengthy procedure in the future, the system was redesigned and modified to a two-valve configuration, enabling future inspections and repairs without warming up the entire linear accelerator (Fig. 1, left, see also p. 48). In addition to replacing the safety valves, a new cryogenic feedbox (X12FB) for later connection of a second injector was installed, allowing the future integration of this injector without another warm-up of the facility (Fig. 1, right).

The first warm-up after 8.5 years of continuous 2 K operation was completed successfully and ahead of schedule. As this was not a risk-free operation, it is considered a huge success. Safety valves were replaced in the injector



Figure 2
Left: Installations behind the SASE2 section in the XTD1 undulator tunnel. Centre: New chicane in the XTD2 undulator tunnel. Right (two pictures): Cabling work in the XTD4 undulator tunnel.

building (XSE), the main accelerator tunnel (XTL), the transfer line and the cryopant. In total, 150 new valves and associated piping were installed, requiring more than 600 new flanges and over 1500 welded connections.

Upgrade of the electron source

The long installation and maintenance period also enabled several upgrades outside the scope of regular maintenance. One of the most significant upgrades concerned the electron source (gun) in the injector. The new radio frequency (RF) gun generation, Gun 5, improved both reliability and performance. Reliability was enhanced through a double in-coupling window for the RF source, optimised geometry to reduce surface fields and improved in-coupling of the photocathode laser. Performance was increased through an internal field measurement probe and an upgraded cooling system that supports higher average power. The new RF gun also required a new RF waveguide distribution. In addition, the laser beam transport system was improved. Together, these enhancements enabled an increase of the RF flat-top pulse length from 600 μ s to 800 μ s, supporting future operational goals.

New and enhanced capabilities

Several upgrades were performed in the undulator tunnels XTD1, XTD2 and XTD4 to improve performance and enable additional scientific capabilities (Fig. 2). Space for future beam manipulation hardware was created in front of the SASE2 undulator by moving the entire undulator system backwards by two cells. The area downstream of SASE2 was modified for the future integration of superconducting undulators as afterburner to achieve even higher photon

energies. Continuing behind SASE2, a new beamline was built to generate and characterise THz radiation created via dielectric tubes and wakefield effects.

In the tunnels for the SASE1 and SASE3 undulators, three new chicanes were installed for beam manipulation to generate intense attosecond pulses and enable high peak brightness and narrow bandwidth via self-seeded radiation also in SASE1. An optical delay line was installed in SASE3 to manipulate the time separation between photon pulses in a two-colour setup of SASE3. Particularly noteworthy are the implementation of additional diagnostics and the optimisation of the lattice at various locations throughout the facility. Altogether, about 300 m of beamline with 350 major beamline components were modified or newly installed.

Maintenance and upgrade of water infrastructure

While the existing cooling capacity met the current facility needs, further expansion or new installations would require an upgrade of the underlying infrastructure. To meet growing cooling-water demands, the water systems for the XTD undulator tunnels were modernised. As the European XFEL stretches from DESY-Bahrenfeld to Schenefeld, this upgrade formed only part of a broader, facility-wide cooling-water modernisation programme, which also included refurbishing pressurisers and safety equipment, overhauling pumps and maintaining the fire-fighting water line.

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Doubling cryogenic safety valves at the European XFEL

Improved safety valve design will enable inspections during cold operation without downtime

The European XFEL cold linear accelerator is classified as pressure equipment and is therefore subject to the requirements of the Pressure Equipment Directive and the German Industrial Safety Ordinance (BetrSichV). As a result, all safety components must be regularly inspected by a certified authority. Verifying the safety valves that protect the linear accelerator and the cryogenic boxes normally requires a complete warm-up of the European XFEL, leading to a facility-wide shutdown lasting several months. To avoid such extended shutdowns of the user facility, the cold safety valves have been doubled to enable their inspection while the accelerator remains in its cold operating state.

Preparation work

Activities related to the doubling of the safety valves began well ahead of the European XFEL shutdown in June 2025. Planning and design were initiated within the DESY Cryogenics group in 2020, followed by the procurement of components in 2023. The manufacturing and installation were outsourced to an external company certified under the European Pressure Equipment Directive (PED, 2014/68/EU) and already familiar with DESY's infrastructure. The

contract was awarded in 2024, allowing sufficient time for the preparation of subassemblies and the organisation of installation activities prior to the shutdown, thereby minimising the actual downtime of the accelerator.

Warm-up

The accelerator was shut down in June 2025, and after eight years of continuous cold operation, the 1.3-km-long

cold linear accelerator was warmed up for the first time (Fig. 1). Anticipated physical effects were addressed through carefully planned procedures based on a comprehensive risk analysis, while unforeseen events were successfully managed through the professional response of experienced cryogenic operators.

Activities in the European XFEL tunnel and at the cryogenic boxes

Following the warm-up and venting of the cryogenic piping, mechanical work could begin, including the cutting and welding required to install the newly pre-fabricated assemblies. A major challenge was the location of the components, which are installed directly above the accelerator's vacuum beam pipe. This required extreme care throughout the installation process to avoid contamination or damage to sensitive equipment. In addition, the confined space and the need to integrate the new assemblies with existing components made the work particularly demanding. The full installation phase lasted approximately three months, including the non-destructive testing required for certification.

In parallel, the safety valves were also duplicated at all cryogenic boxes. The most challenging task here was the removal and installation of the largest valves at the distribution box located on Basement Level 2. In total, approximately 150 safety valves were duplicated across the tunnel and the cryogenic boxes (Fig. 2).

In parallel to these activities, a new cryogenic box (named X12FB) was installed at Basement Level 4 to enable the

future installation of a second European XFEL injector without the need for dedicated shutdown.

Verification of installation work and preparation for cool-down

After completion of the mechanical work by the external contractor, responsibility was handed over to the DESY Cryogenics group for verification of the overall system integrity. Comprehensive helium leak checks were carried out on the newly installed components as well as on selected existing ones, with the aim of minimising helium losses in the linear accelerator, cryogenic boxes and transfer lines. In total, more than 1500 flanges were tested over a period of several weeks by certified personnel. The facility was well prepared for the start of the cool-down on 12 December 2025, and the required documentation is being finalised for review by the certified authority.

Outlook

The successful execution of this complex intervention marks an important step in strengthening the long-term reliability and availability of the European XFEL. By enabling mandatory safety verifications without extended shutdowns, the upgraded safety valve concept supports more flexible operation and ensures continued safe and efficient user operation in the years to come.

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Figure 2

Some of the safety valves of a cryogenic box after the doubling

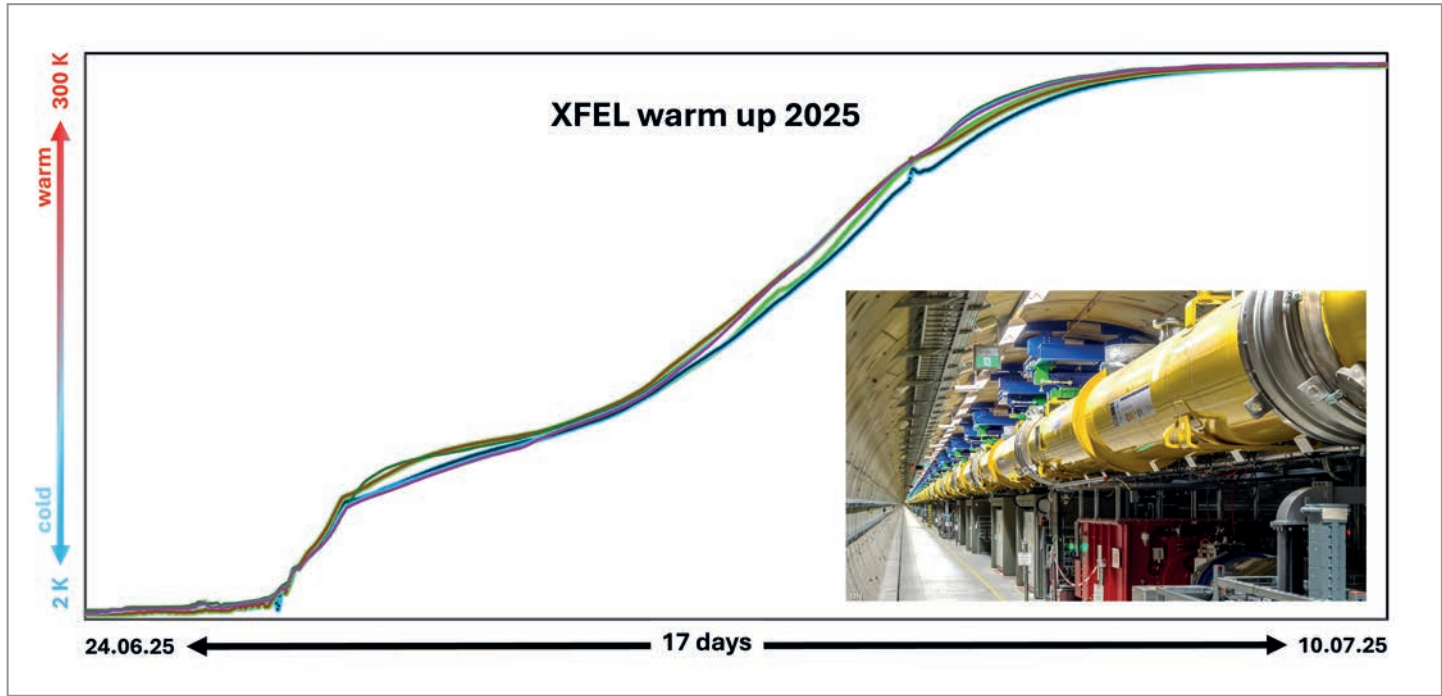


Figure 1
Warm-up profile for different regions (strings) of the European XFEL cold linear accelerator (carried out during the long installation and maintenance period 2025)

Lasing of a cavity-based X-ray FEL

Towards “full” lasing at the European XFEL

Cavity-based X-ray free-electron lasers (CBXFELs) promise to transform the field of hard X-ray science by delivering radiation with exceptional brilliance, stability and full three-dimensional coherence, bringing the properties of optical laser oscillators to the hard X-ray regime. A team from DESY, European XFEL and Universität Hamburg has realised a proof-of-concept CBXFEL featuring a 132.8 m round-trip hard X-ray cavity using diamond crystals in Bragg reflection. This article reports on lasing with multipass gain, about 20 years after the first conceptual idea was proposed.

The problem

State-of-the-art hard X-ray FEL facilities predominantly operate in the self-amplified spontaneous emission (SASE) mode. While SASE enables extremely high peak brilliance, it intrinsically suffers from limited longitudinal coherence and significant shot-to-shot fluctuations. Self-seeding schemes improve spectral purity, but do not fully overcome stability and coherence limitations. CBXFELs overcome these challenges by trapping X-ray pulses in a monochromatising Bragg-reflecting cavity around undulator segments and synchronising them with high-repetition-rate electron bunches [1, 2]. This oscillator scheme generates fully coherent, highly stable and spectrally pure X-ray pulses, analogous to infrared and ultraviolet oscillators, while reducing the need for very long undulator lines. With a

repetition rate in the MHz range, the European XFEL uniquely meets the stringent brightness and repetition rate requirements necessary for this concept.

The cavity

The CBXFEL demonstrator (Fig. 1 and Ref. [4]) was implemented at the end of the SASE1 undulator line using the last four undulator segments with a total active length of 20 m at an electron beam energy of 14 GeV. The optical cavity has a total round-trip length of 132.8 m and is formed by two 100- μ m-thick diamond crystals operating in the (400) Bragg reflection at a photon energy of 6.95 keV. Each crystal is combined with a pair of perpendicular Kirkpatrick–Baez mirrors, creating a retro-reflecting

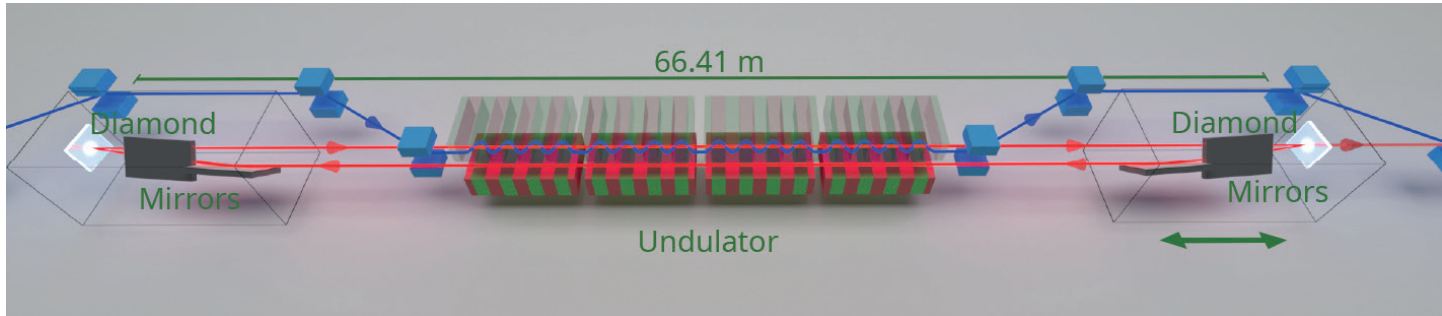


Figure 1
Schematic of the CBXFEL experiment at the SASE1 undulator line of the European XFEL. The X-ray cavity consists of two diamond crystals in Bragg reflection working close to backscattering geometry and two pairs of focusing X-ray mirrors to steer and focus the beam. The surfaces of the crystal and the mirrors are perpendicular to each other, forming a retro-reflector. The downstream retro-reflector unit (on the right) can be translated to tune the cavity length. The electron beam (blue) is injected from the left via a magnetic chicane, and the X-ray pulse (red) is circulating in the cavity, overlapping with electron bunches that pass the undulator at 2.23 MHz. Picture adapted from [3].

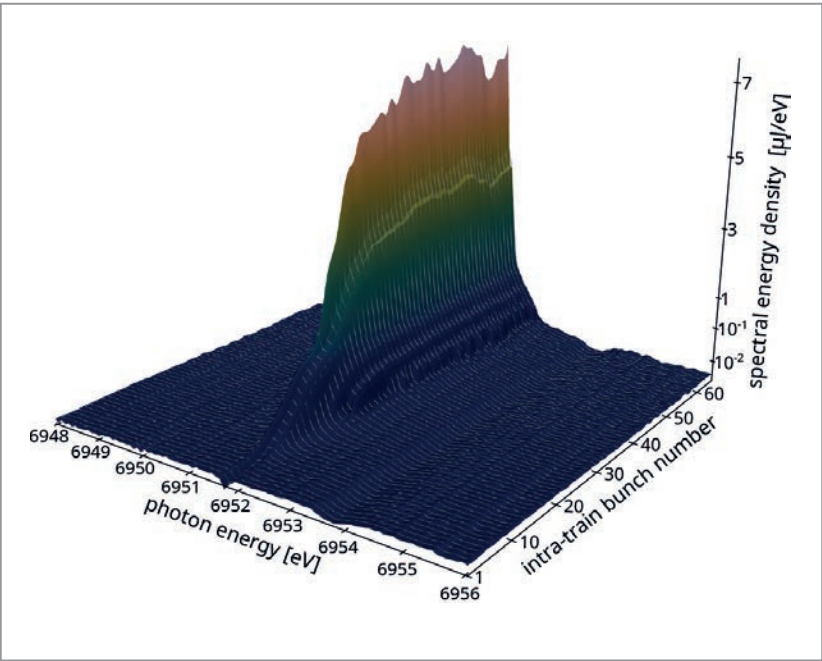


Figure 2
Evolution of the mean spectra per intra-bunch number averaged over more than 1000 radio frequency (RF) pulses. The vertical axis data (spectral energy density) has a custom scaling to highlight both the low signal during the start-up of gain and the maximum signal, exhibiting thermal saturation effects.

geometry that enhances angular stability at the nanoradian level. The downstream mirror–crystal assembly can be translated with micrometre-precision to synchronise the cavity round-trip time with the electron bunch repetition rate.

Making it lase

After spatial alignment of the cavity optics with 100 nrad precision, a cold-cavity ring-down was initially observed, demonstrating stable X-ray pulse storage with a 70% net reflectivity without gain. By scanning the cavity length with micrometre precision, synchronisation between the circulating photon pulse and the electron bunches was achieved. Under these conditions, the recirculating X-ray pulse seeded subsequent electron bunches, resulting in exponential pulse energy growth over successive round trips [5].

Spectral measurements downstream of the cavity show a transition from a broad SASE spectrum for the first bunch to a much narrower and more intense spectrum for later bunches in the train (Fig. 2). The seeded spectra exhibit a bandwidth of approximately 0.24 eV (FWHM) – a narrowing by a factor of 100 compared to initial shots, reflecting the spectral filtering imposed by the diamond Bragg crystals.

What follows

The successful demonstration of lasing with multipass gain in a hard X-ray cavity establishes the feasibility of CBXFELs

at a large-scale user facility. The present proof-of-concept setup only reached single- μ J intensities due to thermal saturation of the uncooled diamond crystal. Hence, it has not yet achieved the peak intensities of state-of-the-art SASE or self-seeded FELs. However, simulations indicate potential for further performance improvements by two to three orders of magnitude through optimisation of electron beam parameters, the use of advanced out-coupling schemes and operation of diamond crystals under cryogenic cooling to approximately 70 K to mitigate heat load effects. The cryocooling will be implemented in the near future.

These developments promise to establish a new source at the European XFEL, moving the free-electron laser closer to its distant sibling, the optical laser oscillator.

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References:

- [1] Z. Huang, R. D. Ruth, Phys. Rev. Lett. 96, 144801 (2006), DOI: 10.1103/PhysRevLett.96.144801
- [2] K.-J. Kim, Y. Shvy'ko, S. Reiche, Phys. Rev. Lett. 100, 244802 (2008), DOI: 10.1103/PhysRevLett.100.244802
- [3] P. Rauer *et al.*, Lasing of a Cavity-based X-ray Source (2025), DOI: 10.21203/rs.3.rs-7274597/v1
- [4] P. Rauer *et al.*, Phys. Rev. Accel. Beams 26, 020701 (2023), DOI: 10.1103/PhysRevAccelBeams.26.020701
- [5] P. Rauer *et al.*, Lasing of a Cavity-based X-ray Source, Nature 650, 93 (2026)

Flat-top laser pulse shaping at the European XFEL

Uniform low-emittance electron slices and data-model-guided framework for laser pulse shaping

Minimising electron beam emittance through the temporal shaping of cathode drive laser pulses is well established. Recently, advanced pulse shaping capabilities were integrated into the NEPAL twin-laser systems, X1 and X2, at the European XFEL, along with a data- and model-driven framework for generating precise temporal profiles. As a demonstration, temporally flat-top-shaped bunches were produced, characterised and used during a user X-ray delivery week. The results showed more uniform slice properties, reduced emittance growth and stable free-electron laser (FEL) lasing. They also highlight the potential of combining temporal and spatial shaping for further emittance reduction in the future.

Emittance characterisation in the European XFEL photoinjector and SASE operation

The temporal profile of the cathode laser pulse strongly influences the initial longitudinal charge distribution of the electron bunch, a key factor in minimising space-charge-induced emittance growth in the photoinjector. To produce electron bunches with a temporal flat-top profile, which is highly desirable for uniform slice properties, pulse shaping capabilities were developed and integrated into the NEPAL twin-laser systems, X1 and X2. Using advanced machine learning techniques, a data- and model-driven

framework was established to generate targeted temporal profiles with high precision while accounting for the effects of electron beam dynamics in the injector. Experimental emittance and matching optimisation were systematically carried out.

Figure 1 shows the measured current profiles and slice emittance distributions for the NEPAL-X1 temporal Gaussian laser (left) and the NEPAL-X2 temporal flat-top laser (right). While the Gaussian bunch exhibits a pronounced emittance increase toward its centre, the

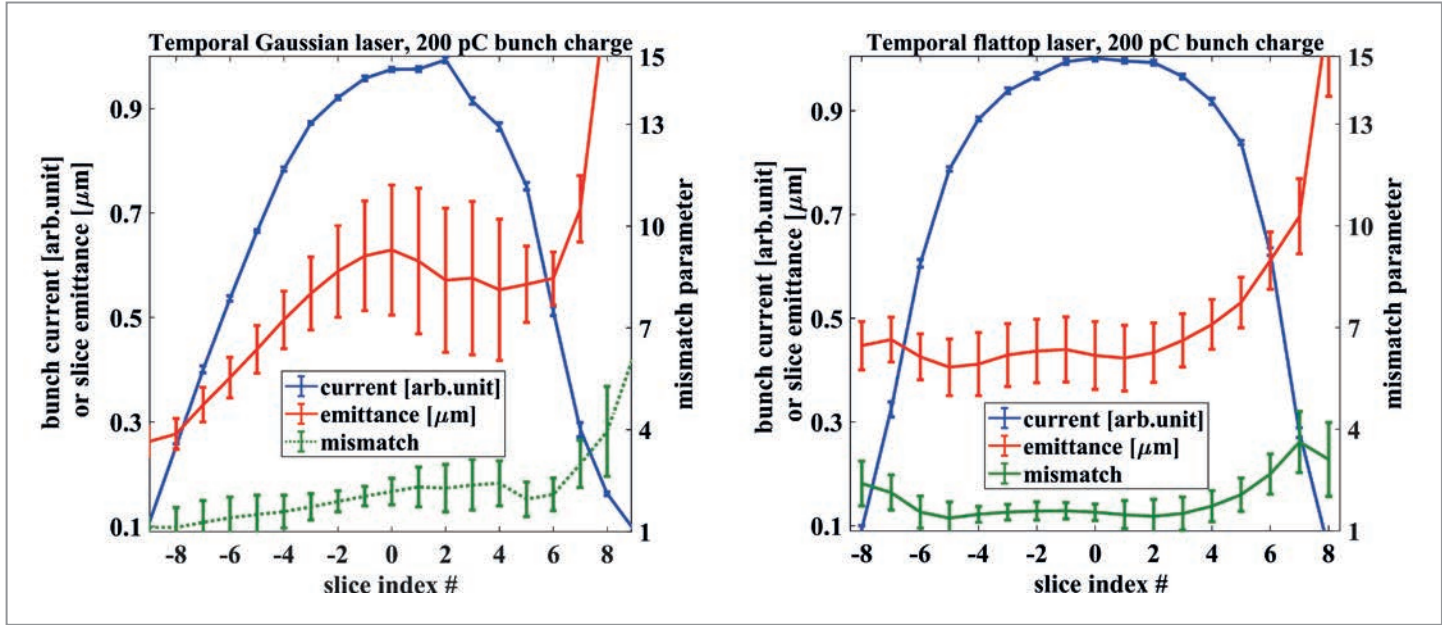


Figure 1 Measured slice emittance of 200 pC bunches in the injector using a temporal Gaussian laser (left) and a temporal flat-top laser (right)

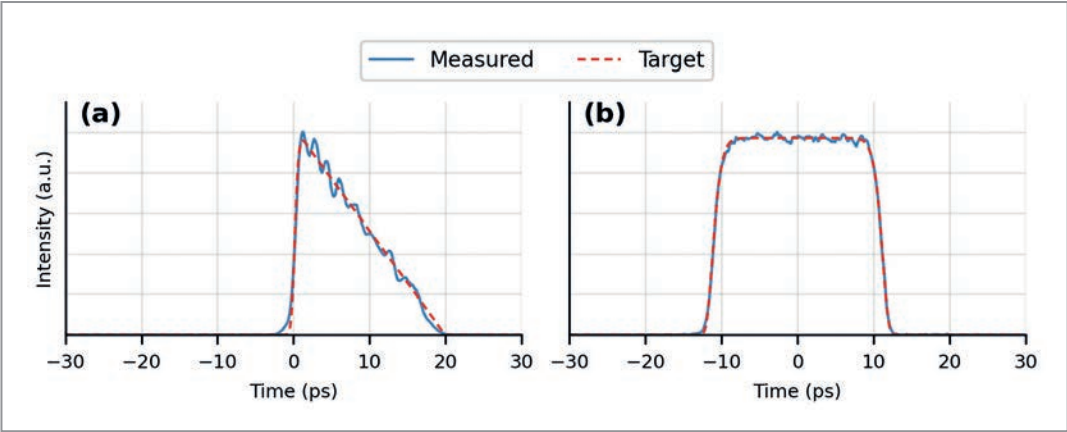


Figure 2 Target laser shapes (red) and resulting laser shapes (blue). Left: Triangular pulse shape. Right: Rectangular pulse shape.

flat-top bunch at the same 200 pC charge shows a significantly flatter and more uniform slice emittance profile, with improved matching throughout. The measured central slice emittance for the flat-top case lies in the range of 0.36–0.49 μm . Considering a thermal emittance of 0.28 μm previously measured at DESY’s photoinjector test facility PITZ in Zeuthen for the same transverse spot size on the cathode, at least 65% of this measured total emittance should be intrinsic. For reference, operating at 100 pC with a smaller initial laser spot yielded central slice emittances at or below 0.3 μm .

Overall, this demonstrates an efficient reduction of space-charge-induced emittance growth, resulting in high-brightness performance of the flat-top-shaped bunch, which, to our knowledge, represents a record achievement for low-emittance beams at this charge level in FEL facilities worldwide. Furthermore, using flat-top-shaped electron bunches, full-scale FEL setup and self-amplified spontaneous emission (SASE) tuning were demonstrated. Photon energies of about 1.7 mJ at 7.1 keV and 7.6 keV were achieved at the SASE1 and SASE2 undulator beam-lines within a short machine optimisation time. Stable photon delivery was accomplished in the following user week.

Data-model-guided framework for laser pulse shaping*

Producing the flat-top electron bunches shown above requires very precise shaping of the drive laser pulse. Because the laser system is complex and changes over time, adjusting the pulse shape by hand is slow and

unreliable. To automate this, a physics-based machine learning control method was developed, which uses a digital model of the laser and continuously updates it with measurement data. This allows the system to learn how to generate a desired pulse shape and to correct itself as conditions change.

With this approach, a wide range of target shapes, such as flat-top, triangular or more complex profiles, can be produced accurately and reproducibly. The method underpins the robust temporal shaping now used in the NEPAL lasers and supports the generation of uniform, low-emittance electron bunches needed for stable FEL operation. Figure 2 shows exemplary target pulse shapes and the achieved pulse shapes justified from the corresponding diagnostic measurements.

Future planning for laser pulse shaping

Starting in 2026, dedicated research and development campaigns on laser pulse shaping will be launched. A primary objective is to integrate temporal shaping with spatial shaping to further reduce the bunch emittance. Laser beamline developments and characterisation of shaped electron beams for FEL operation are foreseen.

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European XFEL superconducting undulator test stand

Paving the way for advanced photon performance with commissioning of the vertical test stand SUNDAE1

European XFEL is exploring the possibility to install superconducting undulators (SCUs) at the end of its superconducting linear accelerator to enhance performance, particularly with a potential high-duty-cycle (HDC) upgrade in mind. SCUs offer higher photon flux and a broader photon energy range compared to conventional permanent-magnet undulators. To support this development, the vertical test stand SUNDAE1 (Superconducting UNDulator Experiment 1), designed for training and for measuring the magnetic fields of SCU coils up to 2 m in length, was installed and commissioned in Hall 3 on the DESY campus in Hamburg.

Layout of the test stand

The SUNDAE1 test stand features a 3-m-long vertical cryostat designed to test SCU coils up to 2 m in length in liquid and superfluid helium at temperatures of 4 K and 2 K, respectively. The cryostat, previously used for testing superconducting cavities during the TESLA Test Facility (TTF) and European XFEL development, has been equipped with a new insert designed by the company Cryovac. This insert includes a top plate with current leads, connections for temperature sensors, cryogenic equipment and the

measurement system required to fully characterise the SCU coils (Fig. 1).

The cryostat is directly connected to the existing cryogenic plant via a new distribution box, which provides helium at two temperature levels: 4–5 K and 70–80 K. SUNDAE1 is also connected to a pump station, allowing the helium bath to be pumped down to approximately 30 mbar (≈ 2 K). A liquid-nitrogen supply line and a nitrogen gas return line are used to cool the thermal shield and the magnet current leads.

It is planned to use SUNDAE1 for training and for measuring the magnetic-field profiles of SCU coils along the magnetic axis. The probes will be mounted on a sledge that moves along high-precision machined rails. The sledge is connected via a titanium rod to a linear motion system manufactured by the company Hositrad, consisting of a single-axis vertical translator with a 2.4 m travel range and a resolution, accuracy and repeatability of 1 μ m.

The cryostat lid is equipped with four current leads rated for a maximum current of 1000 A, four for 500 A and twelve for 20 A. Two bipolar power supplies with ± 1500 A and six 20 A power supplies, each with respective quench detectors, were procured from JEMA. The system allows coils to be powered with a maximum current of 3000 A.

SCU coils will be tested in SUNDAE1, and after quality assurance, they will be assembled in the final operational cryostat.

Commissioning of the cryogenic components

A completely new cryogenic distribution system was developed to supply the SUNDAE1 test stand with liquid helium. The existing cryogenic plant (backup for the FLASH accelerator), dewar and vertical cryostat were refurbished, including the revision of valves, temperature sensors, flow and pressure measurement points, and a new distribution box was designed, manufactured and installed to enable the testing of superconducting coils.

Produced by the company Kriosystem, the distribution box connects the cryogenic plant to the vertical cryostat and the 2000 l liquid-helium dewar via vacuum-insulated transfer lines (Fig. 2). It also provides two additional connections for the future horizontal SCU test stand (SUNDAE2) and the existing superconducting magnet test stand (XMTS). Two further transfer lines allow connection of the FLASH accelerator.

The connection of the distribution box to the cryogenic plant and the vertical cryostat was part of the contract with Kriosystem, while the remaining installation was carried out by the DESY Cryogenics group. This included connecting the vertical cryostat to the existing pump station, to FLASH and to the helium dewar, along with the necessary vacuum-insulated piping and transfer lines.

The complete system was commissioned at 2 K without the Cryovac insert and at 4 K with the new insert at the beginning of 2025. A bypass connection allowed the system to be tested under current. Modifications to the insert were implemented during the year, with the revised insert delivered to DESY in November 2025, ensuring long-term reliable operation of the test stand. A first key milestone has already been achieved: All current leads can be powered to the required current of 1000 A.

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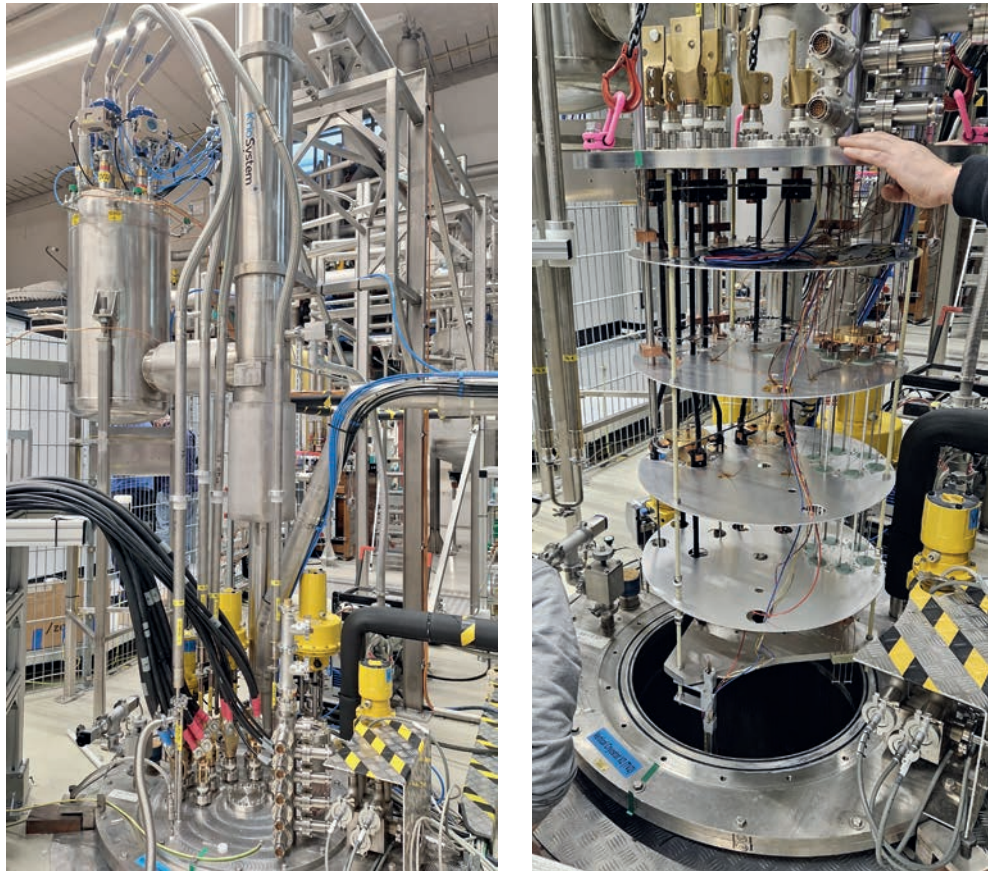


Figure 1
Left: SUNDAE1 test stand.
Right: SCU insert during installation.



Figure 2
The cryogenic plant and distribution box for the SUNDAE1 test stand

SLASH – the FLASH seeding laser

High-power UV laser for MHz repetition rate seeding in burst mode

Recently, DESY's FLASH facility was upgraded to become the first high-repetition-rate free-electron laser (FEL) that is externally seeded to deliver brighter, more stable and coherent vacuum ultraviolet (VUV) pulses. At the heart of the upgrade is SLASH, a new high-power UV laser that imprints its timing and spectral purity onto the electron beam. SLASH generates two synchronised UV pulse trains at 1 MHz within short bursts, with tuneable wavelengths and femtosecond durations, and transports them with high stability to the modulators. The new seed transforms FLASH into a fully coherent high-repetition-rate femtosecond VUV laser, making it the first of its kind in the world and setting a new standard for future FELs.

FLASH at DESY in Hamburg is a unique VUV to soft X-ray light source that works like an ultrafast microscope. A beam of electron bunches, accelerated inside superconducting cavities over hundreds of metres to nearly the speed of light, is guided through special magnetic structures to produce extremely bright, extremely short flashes of VUV light. These pulses are so short in time that they can be used to track electron motion, e.g. in molecules, letting researchers watch chemistry in action and probe materials at the nanoscale. If these pulses also have very narrow spectral bandwidth, scientists can access and distinguish different electronic states that reveal distinct fast chemical changes on femtosecond time scales.

As part of the recent upgrade project called FLASH2020+, the FLASH1 FEL beamline was replaced by a new beamline

that is specifically designed to allow for imprinting the properties of a high-power laser onto the electron beam – a process commonly referred to as external seeding [1]. The photons generated from the seeded electron beams inherit the laser's spectral and pulse energy stability as well as its coherence, all of which are properties that were previously not accessible at high-repetition-rate FELs.

A key component in this process is SLASH, a new, high-power laser system developed and engineered to bring unprecedented stability and coherent control to the powerful VUV pulses produced by FLASH1 [2]. This upgrade does not just improve FLASH; it pioneers a new class of scientific instrument, making it the first of its kind in the world and setting a new standard for future facilities.



Figure 1
SLASH laser room with the SLASH high-power seeding laser system enclosed in the grey boxes

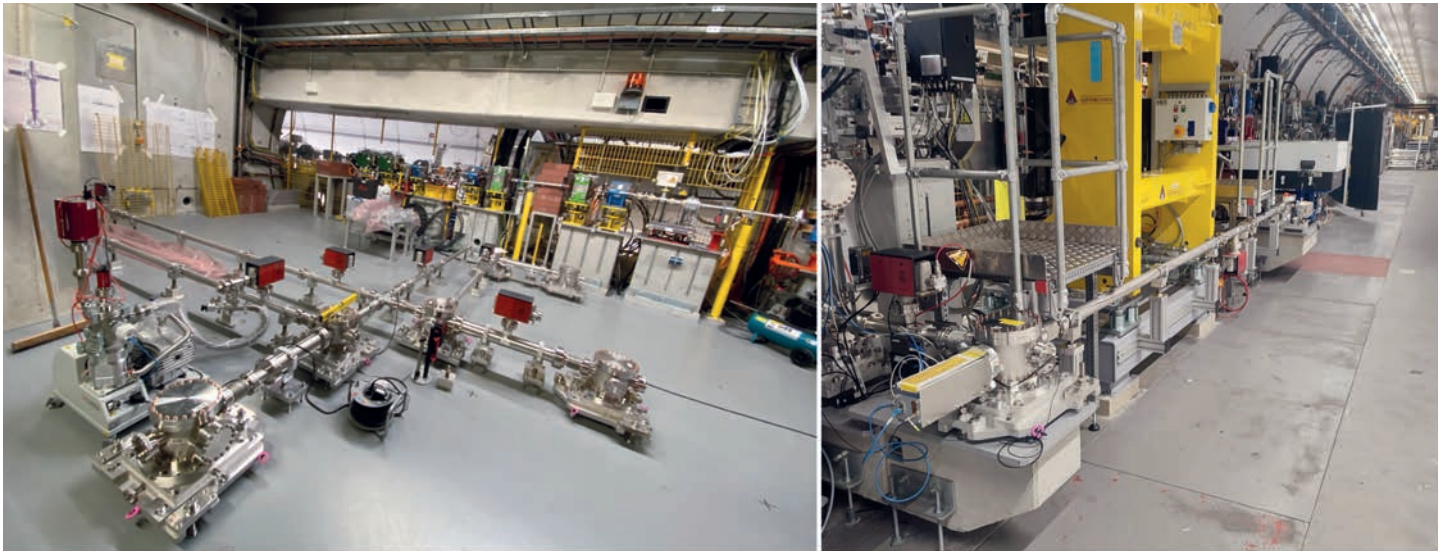


Figure 2
SLASH beam transport system

What is SLASH?

To realise external seeding at FLASH1, SLASH (Seeding Laser for FLASH), a custom UV laser system designed to meet the demanding timing and stability requirements of the seeding process, has been developed at DESY. In simple terms, SLASH starts with a very stable infrared laser, shapes and amplifies it, converts it to UV and sends two carefully timed UV pulse trains into the accelerator, where they overlap with the electron beam. Those two pulses prepare the electrons in such a way that the FLASH1 FEL produces high-energy VUV pulses with far greater regularity, higher brightness and narrower bandwidth than in the self-amplified spontaneous emission (SASE) mode in which it used to operate before the FLASH2020+ upgrade.

Seeding at FLASH uses two schemes: high-gain harmonic generation (HG) and echo-enabled harmonic generation (EEHG). In a nutshell, the high-energy electrons are modulated with two different UV "colours" of ultrashort light pulses at precisely controlled times and wavelengths. Through a sequence of magnetic structures in the FEL, the near-light-speed electron beam then radiates VUV light pulses with excellent coherence, similar to a conventional laser.

What are the numbers?

Technically, SLASH must deliver two UV pulse trains at 1 MHz repetition rate within 0.6 ms bursts, repeating ten times per second. One UV beam (SEED1) has a wavelength of 343 nm with about 500 fs pulse duration; the other (SEED2) is tuneable between 297 and 317 nm with pulses around 50 fs. Both must be precisely synchronised in time with femtosecond precision and overlaid with the electron beam at the micrometre scale.

Figure 1 shows the SLASH laser room. From there, the seed beams are guided through about 40 m of evacuated

tubes to the accelerator tunnel. There, a well-defined object plane in the laser room is imaged exactly onto the centre of the magnetic modulators, where the electrons pass through. This optical relay maintains the beam quality and stability and magnifies the laser spot in the lab to match the size of the electron beam. The laser beam transport system is shown in Fig. 2.

Status and outlook

The SLASH laser system is now fully installed, aligned and operational with limited features. It has already demonstrated its core capability: delivering two synchronised, high-stability UV pulse trains to FLASH1 at 1 MHz burst repetition rate. This marks a major milestone, confirming that the laser, timing distribution, UV transport system and modulator overlap function together as a coherent seeding system. Over the next development phases, the focus will shift to full routine operation and expansion of the laser capabilities. Key future improvements include automated wavelength tuneability across the desired range, timing drift compensation to support 24/7 operation as well as motorised alignment and parameter scans with real-time monitoring, all integrated into operator-friendly remote controls.

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References:

[1] M. Beye *et al*, FLASH2020+ Upgrade of FLASH: Conceptual Design Report (2020), DOI: 10.3204/PUBDB-2020-00465
[2] T. Lang *et al*, Technical Digest Series, CLEO 2025 SS158_2 (2025), DOI: 10.1364/CLEO_SI.2025.SS158_2

FLASH's new personnel interlock

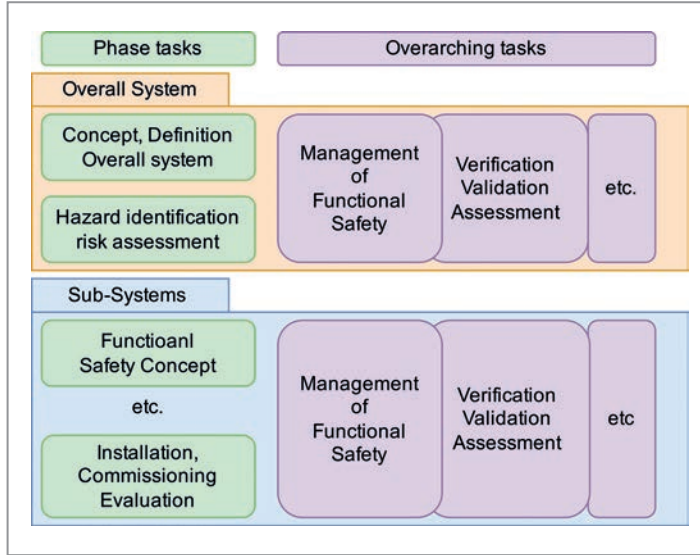
New personnel interlock system for FLASH compliant with Safety Integrity Level 3 is in operation

During the second shutdown as part of the FLASH2020+ upgrade from 14 June 2024 to 1 August 2025, the relay-based personnel interlock system, some parts of which were 20 years old, was replaced by a new, state-of-the-art interlock system based on a programmable logic controller that is compliant with the requirements of Safety Integrity Level 3 (SIL3). At the FLASH free-electron laser facility, the main task of the personnel interlock systems is protection of personnel against ionising radiation produced by the accelerators' components and protection against hazards related to the operation of the magnets. A safety process from risk assessment to verification and validation was followed to specify the safety requirements and evaluate the achieved performance.

Safety process

The service life of safety components is limited, with the manufacturer often specifying a duration of 20 years. As most of the safety components at FLASH had reached this age, renewal of the personnel interlock system during the shutdown was necessary.

In recent decades, the probabilistic approach has become established in both risk assessment and the evaluation of the reliability of safety components, and it has been made mandatory by regulations and the relevant standards on functional safety. As part of the renewal of the FLASH personnel interlock system, the risk assessment process



was implemented accordingly. To this end, DESY's Occupational safety, Radiation Protection and Personnel Safety Systems groups jointly developed a template for a risk assessment table that can be applied to all types of hazards. At FLASH, the risk assessment was coordinated by the responsible FLASH Accelerator group. For the necessary technical measures (safety functions) for risk reduction, a risk analysis with regard to ionising radiation was carried out in accordance with the functional safety standards at DESY. High safety requirements (up to SIL3 according to IEC 62061) were determined for the reliability of the safety functions.

Functional safety standards have further substantiated the requirements for functional safety management in recent years. For example, the four-eyes principle and the associated separation of roles between production and evaluation have been outlined more explicitly to ensure that safety functions adequately control hazards and comply with standards. The roles and their assignment to individuals are defined in a Safety Plan. At DESY, the components of the safety functions are provided by different groups, e.g. groups that provide radio frequency stations, certain ultra-high-power lasers, beam shutters, magnetic power supplies, or others.

Figure 1
Sketch of the process map related to the overall system and the subsystems, e.g. the interlock subsystem. A few phases and overarching tasks are named as examples.

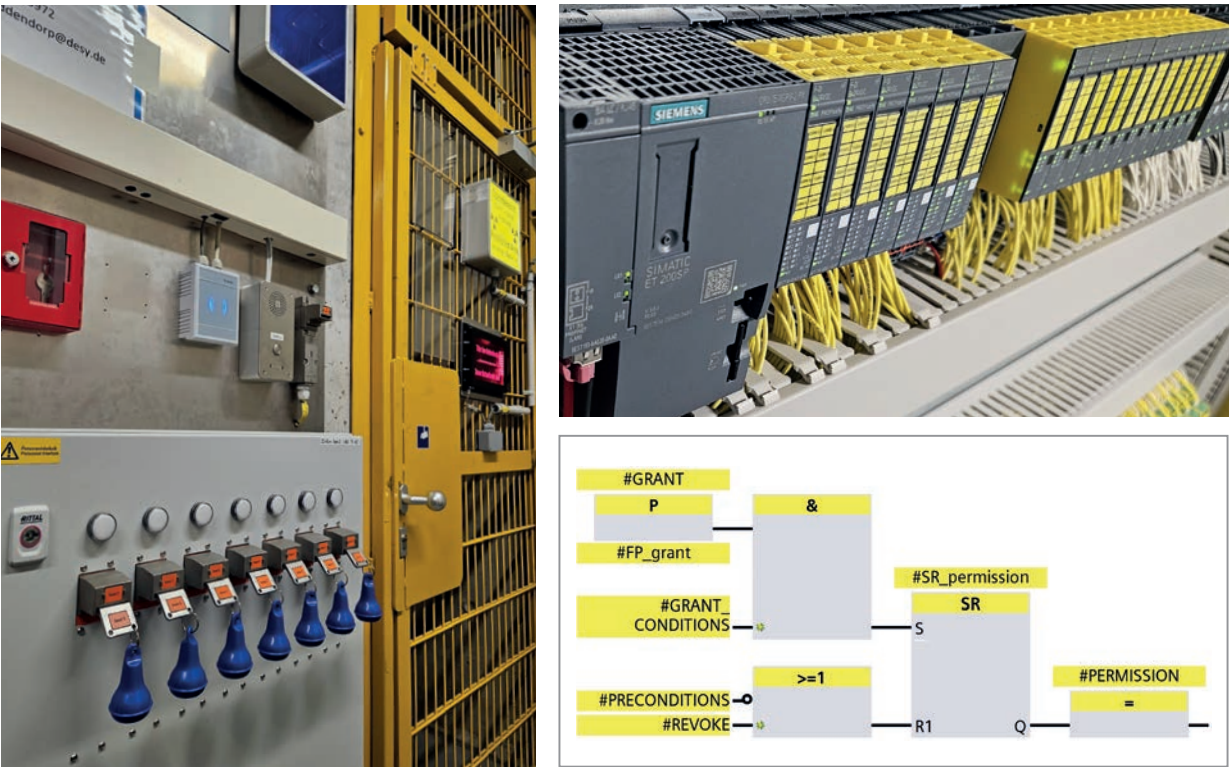


Figure 2
Left: FLASH Seed 2 interlock door with new safety keys.
Top right: Main electronics cabinet showing the safety PLC and I/O cards.
Bottom right: Excerpt from the PLC software using the custom-made permission software module within the FLASH-specific software.

The Personnel Safety Systems group, which is primarily responsible, among other things, for the interlocked areas, sensors and logic solvers, is developing and implementing a safety process that regulates the entire life cycle phases of the safety components for which the group is responsible. The process comprises phase tasks and overarching tasks and covers the overall system as well as the subsystems (Fig. 1). The safety process is managed according to the Safety Plan. The life cycle phases are completed by reviews to ensure that the life cycle objectives are achieved.

The first phase within the life cycle of the safety functions carried out in the group consisted of developing the functional and technical safety concepts based on the results of the risk analysis. These concepts provided the assignment of failure rates to each subsystem within the overall safety functions, ensuring that the maximum permissible overall failure rate of the function is met and all safety requirements are fulfilled. In addition, detailed requirements for the safety components provided by the group were defined.

New PLC-based personnel interlock system

FLASH's new personnel interlock system is based on safety programmable logic controller (PLC) technology (F-SPS by Siemens). This platform supports safety functions up to SIL3 (IEC 62061) or PLe (EN ISO 13849). It provides safety I/O electronic cards and safety-certified software modules to implement the safety function logic (Fig. 2).

The SOFTEMA software assistant [1] was used to support the development and documentation of the FLASH-specific software in accordance with the EN ISO 13849 standard. The group modularised its software and safety-qualified the modules to provide a library that can be reused for various projects (Fig. 2). The entire system logic is described in a specially developed C#-based configuration. A so-called generator was developed to generate the PLC software from the configuration using the module library. This supports reproducibility, extensibility and modifiability, which can be applied to multiple projects as needed to benefit from improvements. As far as the modules are concerned, the generated software underwent the safety process assisted by SOFTEMA for safety qualification, compliance with standards and documentation. New safety-certified components, e.g. the safety key system (Fig. 2) and dynamically monitored safety switches on interlock doors, were integrated.

Conclusion

At FLASH, following a precisely defined safety process, an important step forward has been taken to keep pace with state-of-the-art safety function development.

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Reference:

[1] SOFTEMA software assistant. Publisher: Deutsche Gesetzliche Unfallversicherung (DGUV), Berlin. <https://www.dguv.de/ifa>, Webcode d1082520

Electrons in focus at FLASHForward

Strong, plasma-based electron lenses shown to be compatible with FEL-quality beams

Plasma wakefield accelerators offer a promising, compact route to higher electron energies for X-ray free-electron lasers (XFELs) and particle colliders. However, the intense focusing fields inside the plasma require small beams to ensure emittance preservation [1], which makes beam transport into and out of the accelerator challenging. Passive plasma lenses, which leverage the strong electromagnetic fields in a plasma for focusing, offer a potential solution – a stepping stone between the plasma accelerator and surrounding magnetic optics. A study performed at the FLASHForward beamline at DESY [2] provided the first experimental demonstration of FEL-quality emittance preservation in a passive plasma lens while achieving focusing strengths two orders of magnitude beyond standard quadrupole magnets.

Plasma accelerators pose certain challenges...

Because of their potential for reducing the cost and size of accelerators and facilities for FELs and linear colliders, interest in plasma-based accelerators (PBAs) has grown tremendously in the past decades. Orders-of-magnitude increases in accelerating gradients compared to their radio frequency (RF) counterparts have been demonstrated [3, 4], as have emittance preservation [1] and energy spread minimisation [5, 6] – all of which are relevant for bringing PBAs closer to their intended applications.

However, particularly for particle-beam-driven PBAs based on RF accelerators, the beam delivery and capture systems that surround the PBAs are often orders of magnitude longer than the actual plasma, decreasing the effective accelerating gradient and counteracting the main argument

for using a plasma in the first place. The very tight focusing required to operate a beam-driven PBA tends to make emittance preservation extremely challenging [1] and can itself be a source of emittance degradation. Indeed, emittances are still not routinely preserved.

... which can, possibly, be overcome using more plasma!

It turns out that a potential solution to these issues caused by fundamental properties of PBAs might lie in another type of plasma-based device: passive plasma lenses (PPLs). Operating on the same physical principles as the accelerator, a PPL leverages the very strong focusing wakefields in the plasma to focus the beam. While the beam inside a PBA should be matched, using the focusing wakefields for

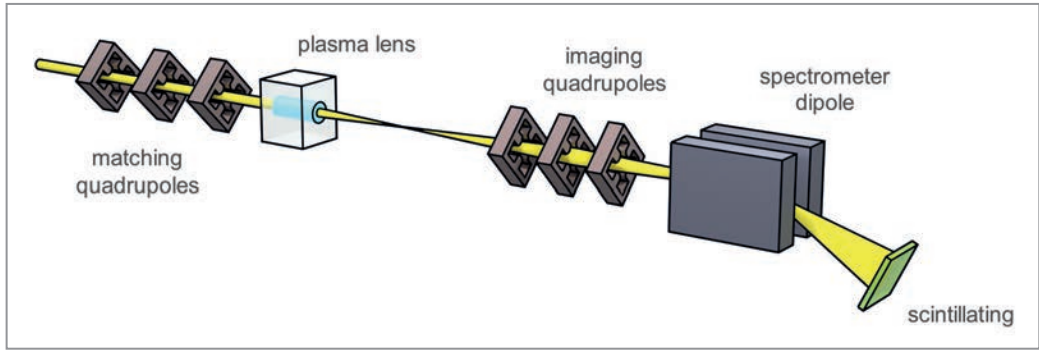


Figure 1 Left: Setup of the experiment. The two bunches, propagating from left to right, were gently focused into the PPL, which was then used to focus them further. The bunches were then imaged at varying imaging settings onto the spectrometer screen, enabling determination of the beam parameters. Right: The 15 mm long, 1.5 mm wide plasma capillary used for the PPL. The capillary was machined out of two mirror-symmetric sapphire slabs, which were joined and mounted in a polyether ether ketone (PEEK) holder (grey-beige) and two copper electrodes delivering the high-voltage pulse that ionised the gas to produce the plasma.

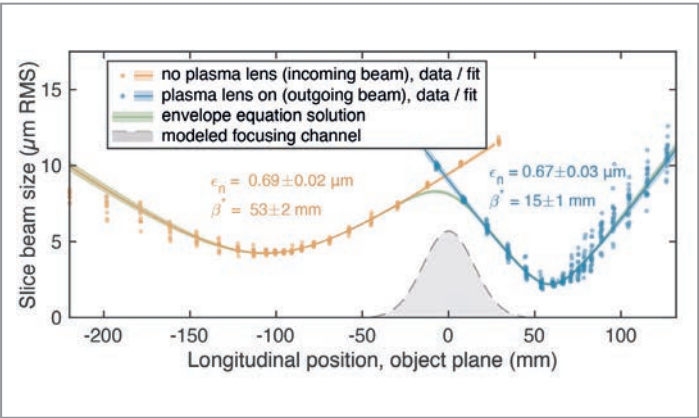
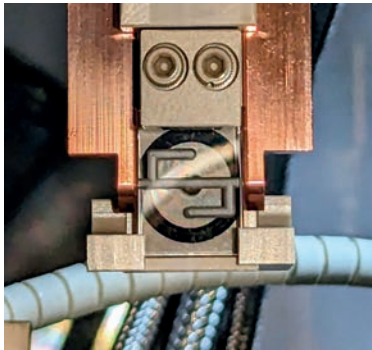
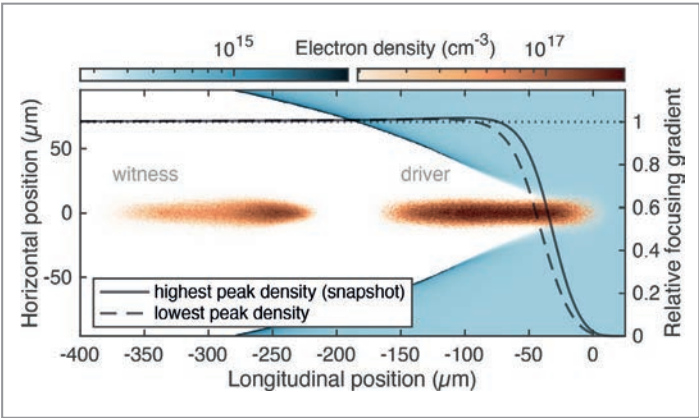


Figure 2 Left: Measured beam sizes (orange and blue dots) and corresponding fits (lines) for the witness bunch, along with the corresponding fit parameters. The green line shows the median of Monte Carlo simulations solving the betatron envelope equation through the Gaussian focusing channel (grey shaded area). Errors indicate the 95% confidence interval of the fits. Right: Snapshot of the simulated beam-plasma interaction in the highest-density working point ($n_{p,0} = 5 \times 10^{14} \text{ cm}^{-3}$). Solid and dashed curves show the on-axis focusing gradient normalised to the nominal blowout gradient for the lowest and highest peak density working points.



confinement and guiding similar to light in an optical fibre, the beam inside a PPL is deliberately larger, resulting in a downstream focus. Their high-strength and wake-based focusing allows PPLs to be placed near the PBA, which minimises emittance degradation. These features are clearly appealing, but while the focusing aspect of PPLs had previously been demonstrated experimentally, their compatibility with high-brightness beams relevant for applications had not. That changed this year.

Demonstrating emittance preservation

The experiment was performed at the FLASHForward beamline at DESY, where single bunches from the FLASH linear accelerator were split into bunch pairs, consisting of a “driver” at the head and a “witness” at the tail, as is the FLASHForward standard. The bunches were focused by quadrupole magnets into a moderate waist at the location of the PPL, rather than the small waist normally employed for acceleration experiments. The experimental setup and the lens capillary are shown in Fig. 1.

The relatively long capillary (for a PPL) permitted the use of a low-density plasma, approximately two orders of magnitude below that commonly used in the plasma accelerator. This ensured that the bunch electron densities were significantly higher than that of the plasma, even at moderately large beam size – which is critical for operating in the “blowout” regime where focusing gradients are linear and emittance preservation is possible. Combined with the use of nitrogen gas, which causes less Coulomb scattering than the more commonly used argon, this allowed the witness emittance to be preserved for approximately half the

bunch (the rest being resolution-limited) while focusing strongly (Fig. 2).

Not only that – by changing the plasma density by a small amount, the focusing strength could be tuned, and moving the lens along the beam axis moved the electron beam focus accordingly, also demonstrating capabilities required to optimise PBA matching and/or capture. The driver bunch was also focused to a large and optimisable extent (Fig. 2), indicating that a PPL might indeed be possible to use for final focusing into a plasma accelerator.

Moving forward

The natural next step is to attempt to employ the PPL in the function it is intended for, as a final-focusing and/or capture device in conjunction with a PBA. A preliminary simulation effort is currently ongoing to inform future experiments.

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Reference:
[1] C. A. Lindström *et al.*, Nat. Commun. 15, 6097 (2024), DOI: 10.1038/s41467-024-50320-1
[2] J. Björklund Svensson *et al.*, arXiv:2509.08420 (2025)
[3] M. J. Hogan *et al.*, Phys. Rev. Lett. 95, 054802 (2005), DOI: 10.1103/PhysRevLett.95.054802
[4] I. Blumenfeld *et al.*, Nature 445, 741 (2007), DOI: 10.1038/nature05538
[5] C. A. Lindström *et al.*, Phys. Rev. Lett. 126, 014801 (2021), DOI: 10.1103/PhysRevLett.126.014801
[6] R. Pompili *et al.*, Nat. Phys. 17, 499 (2021), DOI: 10.1038/s42005-024-01739-x

Active energy compression of laser-plasma-accelerated electron beams

Reducing the energy spread and jitter of plasma electron beams to the permille level

As an integral part of DESY's future project PETRA IV, DESY will build a compact plasma-based injector to inject 6 GeV electron beams directly into the storage ring. Besides the challenge of accelerating electrons to this energy level within only centimetre distance, the energy distribution of these beams has to match the narrow acceptance of a modern fourth-generation synchrotron. DESY has reached an important milestone on this journey by demonstrating active energy compression of a laser plasma-accelerated electron beam in a proof-of-concept experiment. At DESY's LUX laser plasma accelerator facility, electron spectra were compressed by more than an order of magnitude down to the permille level, matching the acceptance criteria of a modern storage ring.

Merging plasma and RF accelerator technology at the LUX experiment
At the LUX experiment at DESY, a 20-m-long extension of the beamline was installed and commissioned in 2024 to demonstrate active energy compression, as proposed in [1, 2, 3]. For the first time, DESY researchers combined a laser plasma accelerator with modern radio frequency (RF) accelerator technology.

The mechanism utilises the inherently short (few femto-seconds) electron beams generated by plasma accelerators and manipulates the longitudinal phase space in two

subsequent steps (Fig. 1). First, a magnetic dipole chicane stretches the electron beams to the picosecond level, thereby sorting the electrons in energy and time. Second, the imprinted time-energy correlation (chirp) is removed by timing the arrival of the stretched beams close to the zero-crossing of the RF field. Higher-energy electrons (arriving early) are thus decelerated, while lower-energy electrons (arriving late) gain energy. When balancing the stretching factor, RF voltage and phase correctly, the chirp can be fully removed, resulting in both (i) a much smaller final energy spread and (ii) a shifting of the beams' mean energy to a defined reference.

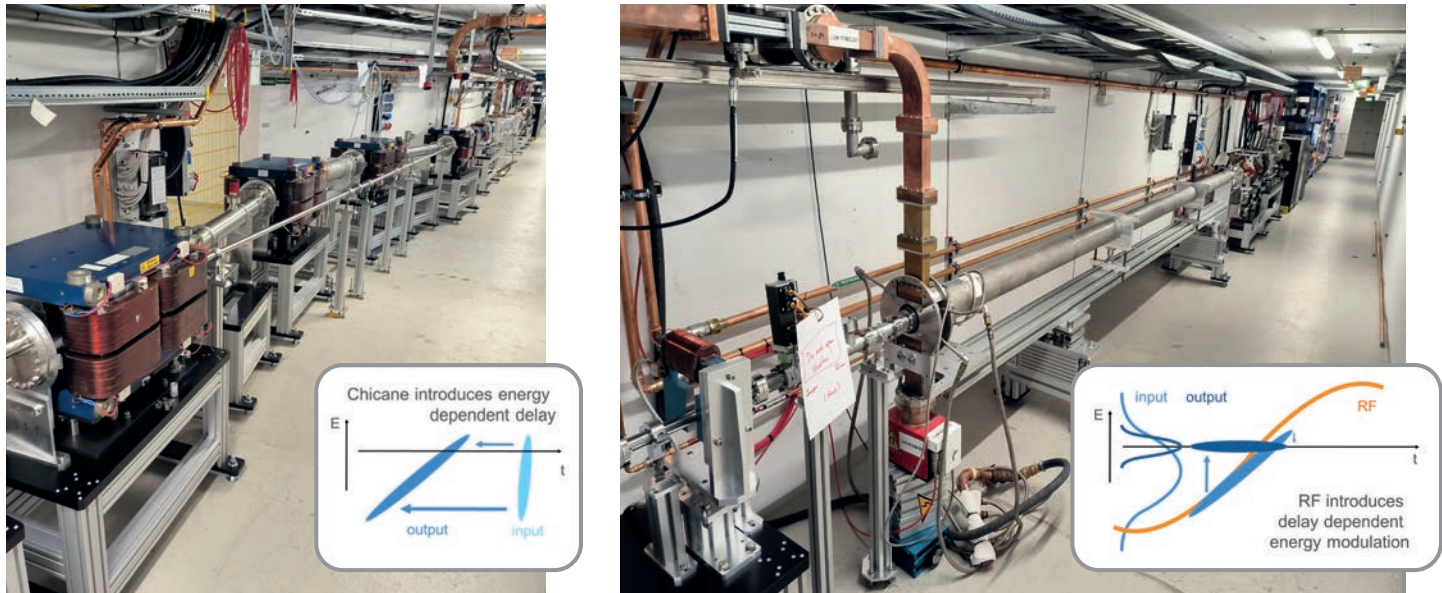
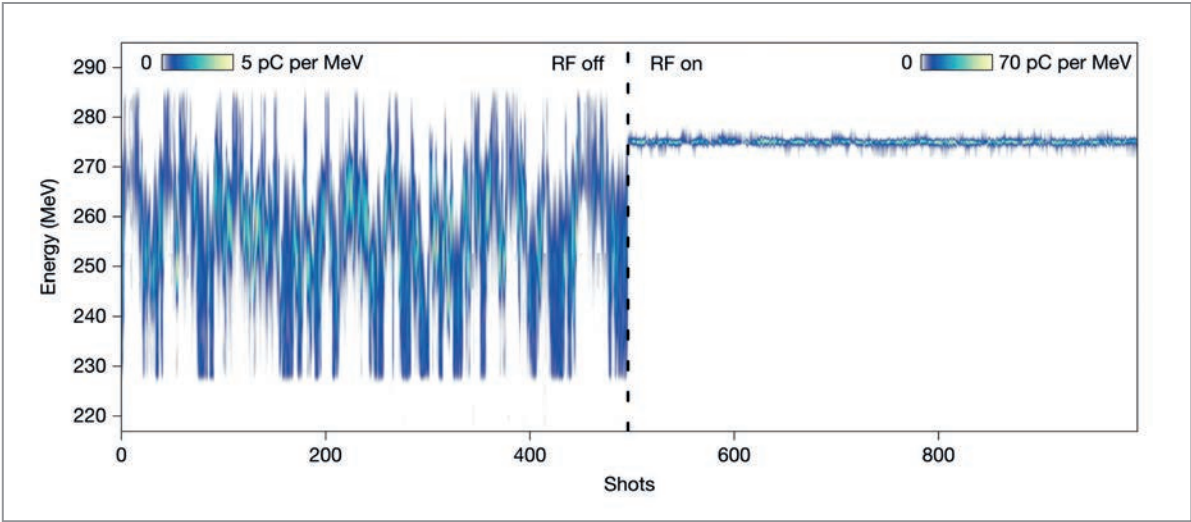


Figure 1
Left: The dipole chicane that stretches the electron beams to the picosecond level, thereby sorting the electrons in energy and time. Right: The chicane is followed by an S-band LINAC II-type RF cavity, compressing the energy spread and jitter of the electrons down to the permille level. The stretching and energy compression are schematically depicted in the insets.

Figure 2
Series of 1000 energy spectra on the electron spectrometer with RF off (left) and on (right) [2], demonstrating a substantial reduction in energy spread and jitter.



Per mille-level energy spread and stability
First energy compression at the new LUX beamline extension was achieved in summer 2024, after only three days of commissioning, demonstrating a reduction in energy spread and improvement in energy stability by more than an order of magnitude (Fig. 2). While this rapid success underlines the robustness of the concept, it was only enabled by the great expertise and excellent support from the many contributing groups across the DESY Accelerator Division and DESY as a whole, combining expertise from different fields. The results were published in May 2025 [4].

Towards a plasma-driven injector
As part of the PETRA IV Preparation Project, activities now focus on a lower-energy prototype plasma injector, with the goal of injecting energy-compressed plasma electron beams into the DESY II booster synchrotron (Fig. 3). The goal is to test and demonstrate the full technology chain of a plasma injector, including important subsystems such as synchronisation, timing and diagnostics, at slightly relaxed conditions, i.e. an injection energy around 300 MeV.

In parallel, DESY's flagship laser KALDERA will be upgraded to its (higher) design laser pulse energy to support the development of plasma waveguide technology, which will enable GeV-level laser plasma electron beams.

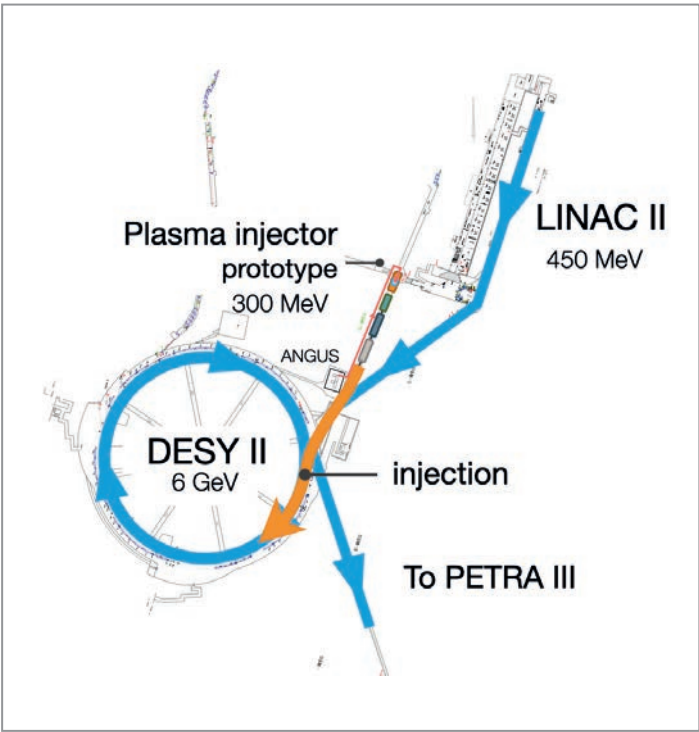


Figure 3
Layout of a plasma injector prototype to inject plasma-accelerated and subsequently energy-compressed electrons into the DESY II booster ring [3]

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References:
[1] S. A. Antipov *et al.*, Phys. Rev. AB 24, 111301 (2021), DOI: 10.1103/PhysRevAccelBeams.24.111301
[2] A. Ferran-Pousa *et al.*, Phys. Rev. Lett. 129, 094801 (2022), DOI: 10.1103/PhysRevLett.129.094801
[3] The Plasma Injector for PETRA IV – Conceptual Design Report, A. Martinez de la Ossa *et al.*, DOI: 10.3204/PUBDB-2024-06078
[4] P. Winkler *et al.*, Nature 640, 907 (2025), DOI: 10.1038/s41586-025-08772-y

Programmatic laser structuring

Key technology for multi-GeV laser plasma accelerators

The efficient generation of multi-GeV electron beams from a laser plasma accelerator requires that the high-intensity drive laser pulse be guided over metre-scale distances. The plasma waveguides necessary for this task are typically created by a second laser pulse focused by a separate optical system. A new approach to structuring the laser pulse for plasma waveguide generation would enable the two laser pulses to be focused by the same optic. This could reduce beamline complexity and enhance stability while also adding tuneability.

Boosting the energy in a laser plasma accelerator

Focusing light to reach high intensities is a critical step in realising a compact laser-driven plasma accelerator. When boosting the energy of the plasma accelerator, for example for a future plasma injector for DESY's PETRA IV project, it is not just one laser focus that is required, but two. The first laser pulse creates a plasma guiding channel similar to an optical fibre, which is used to extend the length of the accelerator. A few nanoseconds later, the second laser pulse is coupled into this plasma waveguide structure and used to accelerate electrons.

Using two laser pulses in this way improves the efficiency of the accelerator but increases the complexity, as two separate focusing systems are usually required.



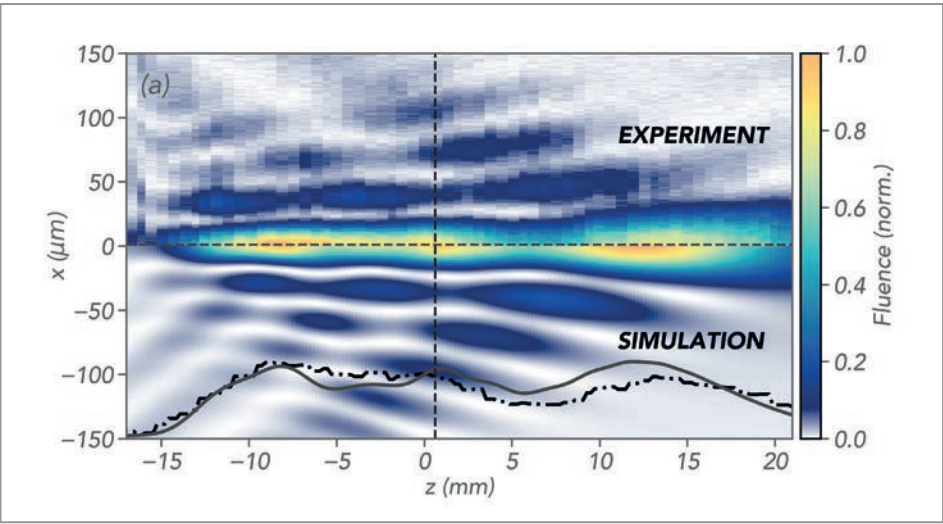
Figure 1
Concept for the scheme: Specific aberrations are added to a deformable mirror placed at a variable distance before the focusing mirror. These aberrations can shape the intensity of the laser pulse in the focal region.

Additionally, the two focusing systems can act to reduce the stability of the accelerated beams, since the overlap of the two laser pulses is crucial.

Programmatic laser pulse tailoring

To overcome these challenges, a new technique has now been proposed and demonstrated [1] to perform both critical tasks with a single focusing optic, offering key advantages over existing approaches (Fig. 1). The technique involves repurposing an existing component commonly found in the optical setup used for plasma acceleration: a deformable mirror. In essence, these mirrors can be programmed to bend and change shape in different ways and are usually used to remove aberrations in the laser beam.

Figure 2
Intensity profile in the focal region of the LUX accelerator. The upper half of the image is the experimentally measured data from a focal scan of the aberrated beam, while the lower half is a simulation, performed with LASY, in which the experimentally set values for the deformable mirror have been added to the pulse.



Instead of being used just to remove aberrations, in this scheme specific aberrations are intentionally added to the laser pulse. When combined with another common optic – a focusing mirror – this shaping scheme allows for the programmatic structuring of the laser focus. With the right combination of aberrations, an elongated focus suitable for creating a plasma waveguide can be formed. Without these extra aberrations, the same focusing optic could be used to thread a second laser pulse through this narrow structure – about the width of a human hair – to accelerate electrons.

Implementation into an existing plasma accelerator setup

The concept was recently tested at DESY's existing plasma accelerator facility LUX [2]. This system includes a deformable mirror installed approximately 34 m upstream of the focusing optic. Despite this long distance between the optics, it was shown that, without any changes to the accelerator infrastructure, it was possible to elongate the high-intensity laser focus from just 4.4 mm to more than 35 mm in length, limited by the range of the diagnostic.

In addition to elongating the focus, the intensity distribution along the focal region could also be tailored. This intensity structuring was achieved by adding small amounts of defocus as well as primary and secondary spherical aberrations to the beam and then allowing it to propagate to – and be focused by – the focusing mirror. The added aberrations were all within the range of the existing deformable mirror even after flattening the wavefront. Importantly, the measured performance could also be reproduced well by simulations using the open-source code LASY [3, 4], led by DESY and LBNL in the USA (Fig. 2).

Benefits for high-energy laser plasma acceleration at DESY

In addition to demonstrating the scheme experimentally, simulations were also performed to explore the operating limits of the technique, showing that the approach could be compatible with the requirements of a future PETRA IV plasma injector. Importantly, the new focusing scheme should enable the two laser pulses – waveguide-forming and drive laser – to both be focused by the same final-focusing optic. It is hoped that this development will significantly reduce beamline complexity and cost while increasing stability.

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References:
[1] P. Blum *et al.*, Opt. Lett. 51, 9–12 (2026), DOI: 10.1364/OL.579664
[2] N. Delbos *et al.*, Nucl. Instrum. Meth. A 909, 318–322 (2018), DOI: 10.1016/j.nima.2018.01.082
[3] M. Thévenet *et al.*, arXiv:2403.12191 (2024)
[4] <https://github.com/LASY-org/lasy>
[5] Structured Plasmas for Laser-Driven Control of Electron Beams – Deutsche Forschungsgemeinschaft (DFG), Project Number 531352484

The development of this focusing scheme was supported through the Emmy Noether Programme of the German Research Foundation (DFG) via the Structured Plasmas for Laser-Driven Control of Electron Beams (SPLICE) project [5], which aims to develop plasma sources for generating high-quality and high-energy electron beams suitable for driving a compact water-window X-ray free-electron laser or for injection into a conventional storage ring.

KALDERA is DESY’s flagship laser for driving a new generation of laser plasma accelerators. By operating at repetition rates far beyond those of previous systems, it enables active feedback on time scales short enough to suppress instabilities arising from environmental fluctuations. In 2025, KALDERA produced its first electron beams with 100 MeV energy at 100 Hz repetition rate, marking a major milestone for the project.

Establishing a new operating regime

Laser plasma accelerators (LPAs) operate at extremely high field gradients on the order of 100 GV/m, enabling compact particle sources for science, medicine and industry. While the technology has advanced significantly, further progress and practical deployment are now limited by the low repetition rates of today’s high-power laser systems. Operating at only a few shots per second restricts the average beam power available to applications and prevents the effective suppression of laser-driven instabilities.

Scaling the repetition rate is therefore a decisive step in advancing LPAs toward technological maturity. DESY addresses this challenge through the development of the KALDERA laser system, which is designed to deliver

100 TW peak power pulses at repetition rates of up to 1 kHz. This establishes a fundamentally new operating regime for LPAs, which enables stable and reproducible performance through the use of active feedback techniques, following principles long established in the radio frequency (RF) accelerators that drive DESY’s user facilities.

Developing a high-average-power LPA

KALDERA is being realised in three phases, increasing the repetition rate and pulse energy step by step. Its development requires addressing major technological challenges, ranging from high-power pump laser integration and cryogenic amplifier design [1] to ultrashort pulse compres-

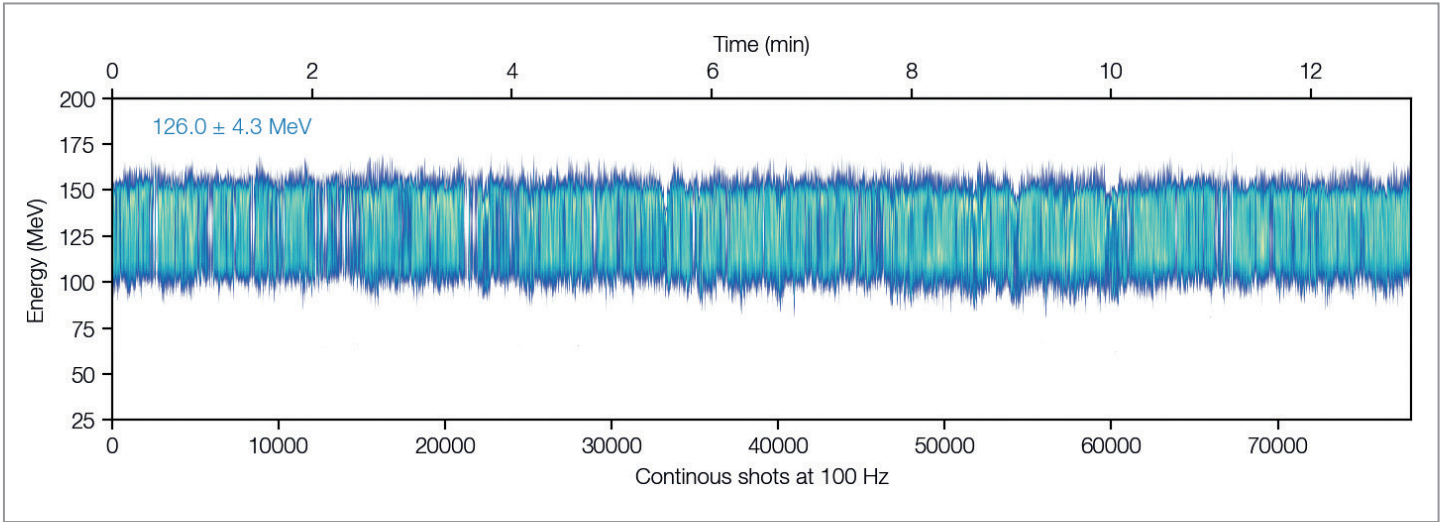


Figure 2
Plasma-accelerated electron beams from KALDERA, reaching energies of around 126 MeV at a repetition rate of 100 Hz. Shown are single-shot electron energy spectra recorded over approximately 12 minutes. The data were taken during the initial commissioning phase of MAGMA, and the accelerator had not been optimised for low energy spread.

sion at kilowatt-level average power [2]. After completion of the first phase in 2024, the laser now delivers pulses of 500 mJ energy with 30 fs duration at 100 Hz repetition rate to MAGMA, the first laser plasma accelerator specifically designed for high-average-power operation at DESY (Fig. 1).

Inside MAGMA, the laser is focused to a 10 µm spot into a millimetre-scale plasma source supplied with a continuous gas flow. Each of the intense laser pulses ionises the gas and drives a plasma wave that captures and accelerates electrons to hundreds of MeV energies over very short distances.

Pushing laser plasma acceleration to kilohertz-level repetition rates required a fundamentally new system design, as no established benchmarks exist for this operating regime. The plasma source was engineered to withstand the concentrated laser power through active cooling and careful material selection. Surrounding infrastructure, from large-scale optics and custom optomechanics to a differentially pumped vacuum system, was developed to ensure stability, durability and controlled heat dissipation. Together with high-sensitivity laser and electron diagnostics operating at the full repetition rate, these elements form a robust platform for continuous accelerator operation at high average power.

exceeding 100 MeV energy at a repetition rate of 100 Hz (Fig. 2). The accelerator now operates reliably over many hours, marking entry into a previously unexplored regime for laser plasma acceleration.

At these repetition rates, unprecedented volumes of data become available. In only about 15 minutes, MAGMA produces as much data as earlier LPAs operating at 1 Hz would collect in an entire day. Full control system integration combined with event-based data acquisition at 100 Hz enables complete shot-by-shot characterisation of the acceleration process. This data richness makes it possible to resolve even subtle correlations between laser fluctuations and electron beam properties – a prerequisite for deploying active feedback systems.

The next major step, planned for 2026, is to close loops between diagnostics and laser actuators to actively stabilise the machine, with the goal of demonstrating sub-percent energy stability. In parallel, development of KALDERA Phase 2 is under way, which will increase the available pulse energy on target to 3 J. Together, these advances position KALDERA as a key platform for bringing laser plasma accelerator technology to maturity.

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References:
[1] T. Eichner *et al.*, Opt. Lett. 50, 4890 (2025), DOI: 10.1364/OL.564062
[2] C. Werle *et al.*, Opt. Express 31, 37437 (2023), DOI: 10.1364/OE.501093



Figure 1
KALDERA’s first laser plasma accelerator MAGMA. Left: Interaction chamber, laser diagnostics and electron beamline. Centre: Final-focusing optics in vacuum. Right: High-average-power plasma source.

The SINBAD-ARES linear accelerator

Accelerator R&D facility for technology developments and medical applications

In 2025, the Accelerator Research Experiment at SINBAD (ARES) linear accelerator was used to perform accelerator research and development with internal and external users. The EIC Pathfinder project THz Wave Accelerating Cavity (TWAC) and studies for advanced beam diagnostics were successfully continued. Medical experiments with living cancer cells irradiated by the high-energy, extremely stable electron beam were performed within a collaboration of the University Medical Center Hamburg-Eppendorf (UKE) and DESY. Dosimetry requirements for medical applications were carefully studied with partners from the DESY Radiation Safety group, UKE and the University of Wollongong, Australia.

R&D activities at ARES

As one of the Helmholtz Accelerator Research and Development (ARD) test facilities, ARES has been used on a regular basis for various internal and external accelerator research and development projects. For example, the DESY Accelerator Diagnostics and Instrumentation group carried out studies on resistive wall current monitors and diagnostics using Cherenkov light with ARES. These were complemented by the development and testing of ultra-

compact longitudinal beam diagnostics that make use of different radiation fields (e.g. coherent transition radiation). Within a collaboration with the University of California, Los Angeles, these techniques were studied in several beamtimes (Fig. 1).

ARES was also used for laser developments by the DESY Laser Science and Technology group. The DESY Radiation Protection group regularly tested, developed and bench-



Figure 1
Diagnostics beamtime with collaboration partners from UCLA

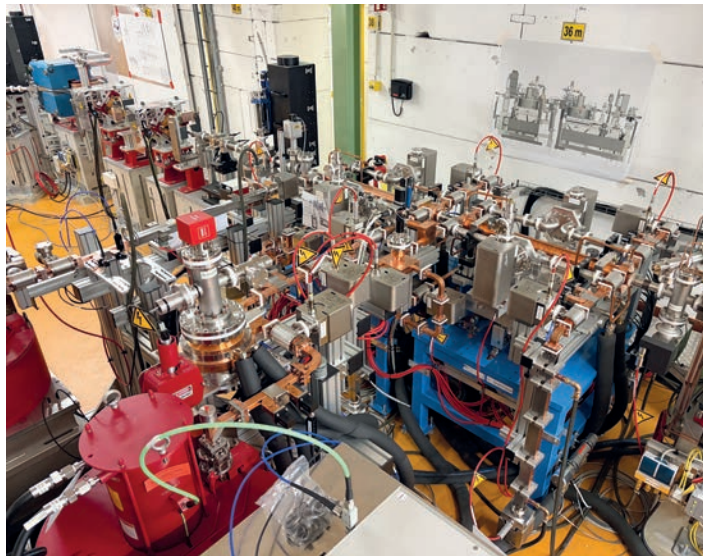


Figure 2
PolariX TDS installation: The polarisable TDS will allow for highest-precision longitudinal diagnostics at ARES.

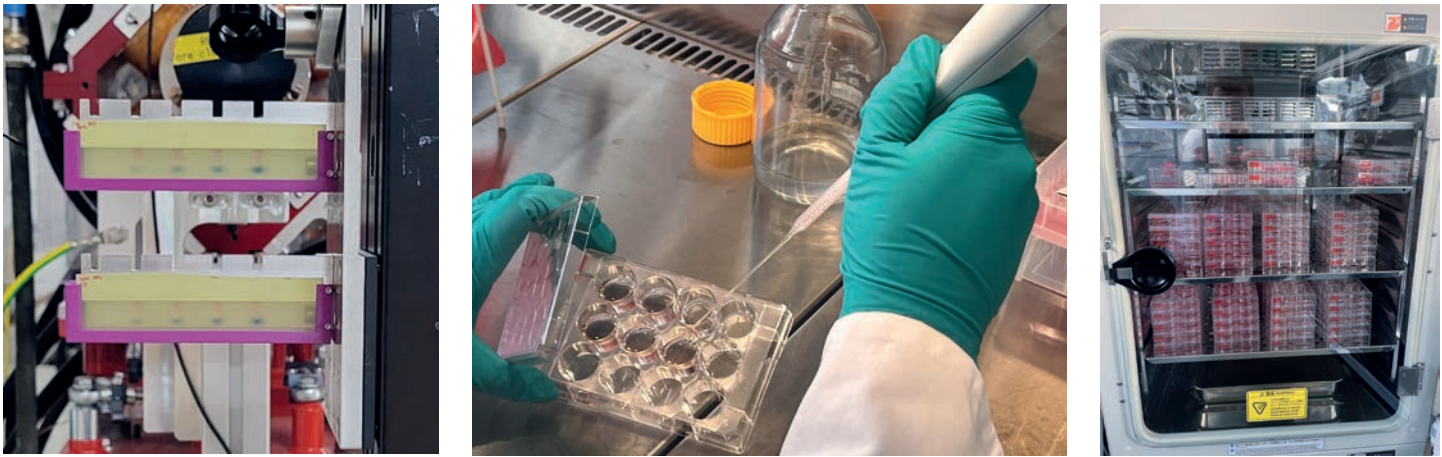


Figure 3
Tumour cell irradiation setup in the in-air experimental area of ARES. The cells are placed in Eppendorf tubes. Left: The dose deposition is visible at the dark spots on a dosimetry film in front of the tubes. Centre: Afterwards, the cells are prepared in petri dishes. Right: The cells then get transferred and stored in an incubator.

marked novel dose rate monitor systems (NitroFLASH, a Hi-Acts project together with DESY’s PITZ photoinjector test facility in Zeuthen and with the University of Erlangen-Nürnberg) and the campus-wide PANDORA radiation protection systems at ARES in 2025. Beamtime was also granted to the FLASHForward team to test and study different diagnostic screen materials.

After first measurement campaigns in 2024, the European EIC Pathfinder project TWAC continued its successful progress by demonstrating passive streaking of the electron beam and enabling longitudinal bunch reconstruction. The respective diagnostic device with a combination of single-digit femtosecond resolution, compactness and minimal complexity is now ready for installation at IJCLab in Paris, France.

One example of a project that has progressed from the research and development stage to application in user facilities is the novel fibre-based beam loss monitoring system. It was tested and optimised at ARES and will now be installed at the “R-Weg” extraction line of the DESY II synchrotron.

In 2025, two X-band PolariX transverse deflecting structure (TDS) radio frequency stations were successfully installed and carefully prepared for commissioning, creating unique and promising possibilities for highest-precision longitudinal beam diagnostics in 2026. The installation is shown in Fig. 2.

Medical applications

Work on medical applications successfully continued in 2025 with beamtimes to irradiate living tumour cells carried out by oncologists from UKE. The goal is to treat medulloblastoma cancer cells – an aggressive brain cancer that mainly occurs in children – with novel treatment methods (FLASH radiotherapy).

The cells were irradiated with different doses and then prepared for further analysis in the biology laboratory in the PETRA III experimental hall “Max von Laue”. Figure 3 shows a typical radiation treatment and analysis process. Numerous statistics were collected, which are now being prepared for publication.

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Attoseconds for accelerators

Radio frequency controls based on carrier suppression detection in accelerators

Modern linear accelerators can produce electron bunches with femtosecond pulse durations. The radio frequency (RF) cavity fields must be controlled with femtosecond precision in phase and 0.01% in amplitude to achieve stable bunch profiles and arrival time conditions for ultrashort bunches. Despite lately improved RF control algorithms and state-of-the-art analogue-to-digital converters, attosecond resolution seemed unobtainable. The DESY Beam Controls group applied carrier suppression interferometry (CSI) for the first time to RF controls to operate a TESLA-type superconducting cavity at DESY's Cryomodule Test Bench (CMTB). The short-term field stability was improved by more than one order of magnitude to approximately 200 attoseconds compared to standard field detectors. The research combines conventional receivers with carrier suppression detectors in continuous-wave (CW) operation to achieve this key milestone towards attosecond stability, which is particularly relevant for pump-probe experiments in free-electron lasers (FELs).

Novel application to RF controls

Pump-probe experiments at FELs with a resolution below 10 fs require ultrashort electron bunches with excellent longitudinal phase space and timing stability. This, in turn, necessitates RF fields with excellent short- and long-term stability in the accelerating cavities. For this purpose, an RF control system regulates the amplitude and phase of the RF fields to eliminate noise and disturbances mainly caused by the high-power RF system.

Today's field detectors are based on heterodyne receivers, where analogue-to-digital converters are the main



Figure 1
CMTB facility at DESY

limitation to achieving attosecond resolution. For this reason, the DESY Beam Controls group extended a standard RF control system for the first time to include a CSI-based receiver providing attosecond resolution [1]. The tests were performed at the CMTB at DESY (Fig. 1), driving a superconducting cavity at 1.3 GHz at a gradient of 8 MV/m and with a loaded quality factor of 10^7 . Figure 2 shows the standard RF control system (marked in yellow) extended by a so-called in-loop CSI. To verify the regulation performance of the combined system, an out-of-loop CSI with a resolution of about 64 attoseconds was used.

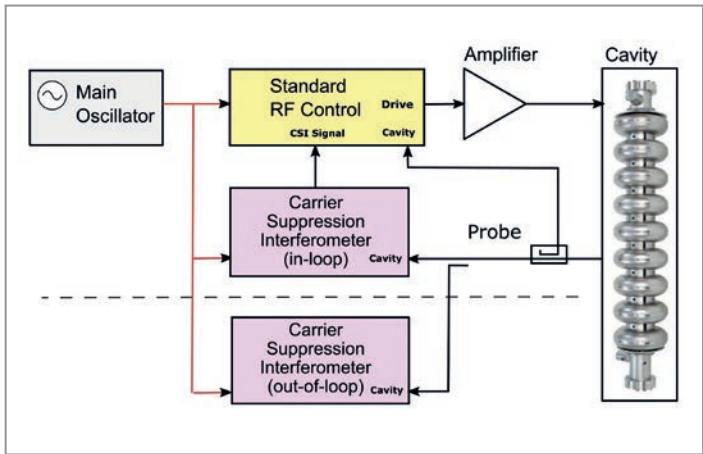


Figure 2
Extension of a standard RF control system by a carrier suppression detector to achieve a regulation performance in the attosecond range. An additional out-of-loop detector is used for verification.

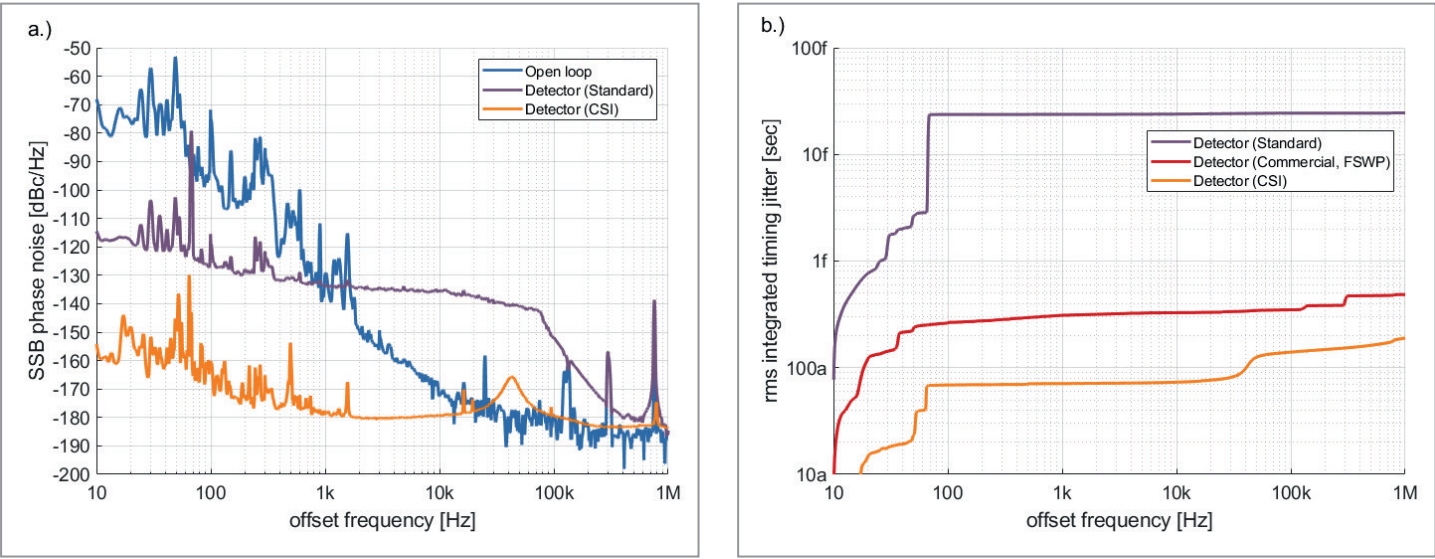


Figure 3
(a) Phase noise and (b) integrated root mean square (RMS) time jitter of the cavity field stability for different detectors. When using the CSI detector, the stability is improved by more than one order of magnitude to approximately 200 attoseconds. Even the best commercial analysers that use cross-correlation cannot resolve this.

Measurements on the attosecond level

Figure 3a shows the cavity field phase noise spectrum for different in-loop field detectors. Without feedback regulation (blue curve), cavity microphonics and the noise of the high-power amplifier (inductive output tube) dominate and accumulate a time jitter of more than 600 fs in the frequency range of 10 Hz to 1 MHz. When the feedback loop is closed using a standard detector (purple curve), the cavity field noise accumulates to about 25 fs (Fig. 3b), limited by the detector and distortions. When using the CSI (orange curve), the cavity field stability is improved by more than one order of magnitude to approximately 200 attoseconds. Commercial phase noise analysers (red curve), even when using cross-correlation techniques, cannot resolve the performance of the CSI detector.

Detailed noise analysis shows that noise contribution from the RF facility reference is crucial on a noise floor level of -180 dBc/Hz in a frequency range between 1 kHz and 100 kHz. To achieve high noise suppression of the high-power drive amplifier, the regulation is operated near the instability threshold, which results in a significant noise contribution at 40 kHz, known as the waterbed effect. Lower regulation gains, combined with reduced cavity microphonics and high-power amplifiers with lower noise, are beneficial for mitigation. Solid-state amplifiers are promising candidates.

Future perspectives

Carrier suppression detectors can thus potentially control

cavities in accelerators with attosecond precision. By operating a single superconducting cavity at 1.3 GHz in CW mode at the CMTB, an integrated time jitter of about 200 attoseconds was demonstrated, outperforming today's short-term superconducting cavity field stabilities by more than one order of magnitude. Providing destructive interference is much easier for continuous than pulsed RF signals. Thermal noise limitations additionally require an output power of at least +20 dBm from the pick-ups of the cavity.

Demand for main oscillators with reduced $1/f$ noise far below -180 dBc/Hz and improved high-power chains with phase noise below -160 dBc/Hz will grow. Further sub-system optimisations for amplitude noise are needed. In addition, RF components for automated destructive interference must be invented. Because state-of-the-art commercial analysers do not resolve time jitter values below 500 attoseconds for any RF component characterisation, the development of measurement prototype systems using cross-correlation for residual and absolute phase noise measurements has to be driven forward.

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Reference:

[1] F. Ludwig *et al.*, Phys. Rev. Accel. Beams 28, 072803 (2025), DOI: 10.1103/jhc3-dtzw

The SHOGWAVE project

Search for high-frequency gravitational waves using superconducting radio frequency cavities

To date, no operating experiment is conducting a systematic search for gravitational waves (GWs) across a significant portion of the frequency domain above the sensitivity range of LIGO and Virgo, the large-scale laser interferometers that have detected GWs at low frequencies. Therefore, the development of a new experiment aimed at searching for high-frequency gravitational waves in the range from 10 kHz to 100 MHz has been initiated at DESY. The basic concept is to use superconducting radio frequency (SRF) cavities to detect the tiny harmonic deformations induced by GWs, which modify the boundary conditions of the oscillating electromagnetic field and lead to a measurable energy transfer between two eigenmodes of the resonator. A Hamburg-led international collaboration is pursuing this effort and has achieved several milestones over the past three years.

Searching for gravitational waves

GWs open a new window on the universe by revealing cosmic events – such as black hole mergers or supernovae – that are invisible to conventional telescopes. First directly observed in 2015 by the LIGO experiment, a laser interferometer in the USA with two 4-km-long arms arranged in an L-shape, these waves momentarily stretch and compress space itself. An alternative approach is now regaining attention: detecting GWs via frequency shifts in resonant cavities rather than interference patterns. Recently, renewed interest in this once-promising method has sparked, reviving a field that had largely faded from focus over the past two decades.

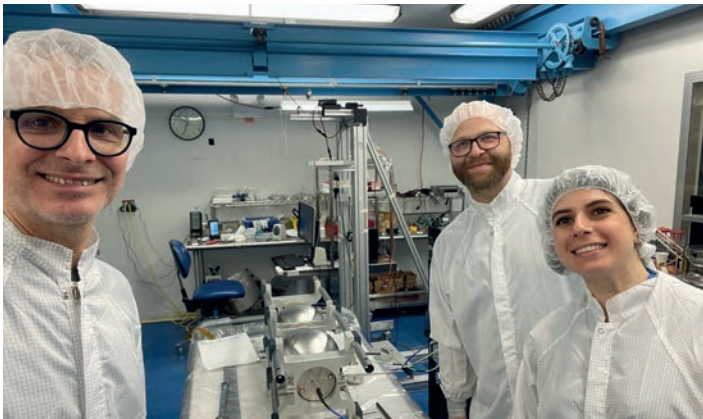


Figure 1
Members of the SHOGWAVE collaboration with the prototype cavity at Fermilab during tuning and before the cold RF measurement. The tuning proved challenging, as the fundamental drive mode and the signal mode were specified to be only 10 kHz apart. This frequency spacing is extremely sensitive to the shape accuracy and cannot be directly measured at room temperature. It was only thanks to the experience gained by the two laboratories in the cavity production for the European XFEL and LCLS-II that the cold test could be successfully prepared.

Dusting off a prototype

It is quite common for research equipment to end up in display cases and exhibition halls: Decommissioned prototypes, visually striking particle detectors or innovative new developments help explain science and serve as technological witnesses of their time. By contrast, it is rather rare for exhibition objects to make their way back from a display case into a research centre. At DESY, however, such an exhibition object has recently begun its second life: a prototype cavity that had previously been on display in Genoa, Italy, for 20 years, the remnant of the PACO project [1].

With the establishment of the Superconducting High-frequency cavities for the Observation of Gravitational WAVes (SHOGWAVE) project – a collaboration of the Quantum Universe Cluster of Excellence of Universität Hamburg, various groups in the Particle Physics and Accelerator Divisions at DESY, INFN Genoa and Fermilab in the USA – this prototype has now been reactivated, and the first commissioning of the cavity after its fabrication more than 20 years ago has started [2].

Cryogenic tests and LLRF control development

After warm commissioning, the cavity underwent surface treatment at Fermilab and Argonne National Laboratory, followed by a first cryogenic test at Fermilab (Fig. 1), which proved the success of the cavity preparation. At the beginning of 2025, the cavity arrived at DESY, and a digital low-level radio frequency (LLRF) control system for the test stand was developed, which allowed two cryogenic tests in the Accelerator Module Test Facility (AMTF) at DESY. The Micro Telecommunications Computing Architecture (MicroTCA)-based system successfully drove the high-quality-factor (high-Q), narrow-resonance 2.1 GHz cavity



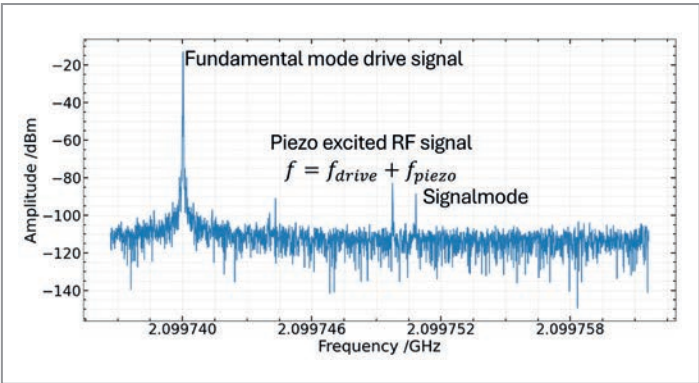
Figure 2
Left: Prototype cavity being installed in a helium bath cryostat in the AMTF facility at DESY. Right (top): Newly developed frame for a set of piezo actuators for generating artificial GW signals and measuring mechanical properties at cryogenic temperatures. Right (bottom): The plot shows the cavity spectrum with a clear peak at the fundamental mode of the cavity, around 2.09974 GHz, and the peak of the signal mode around 11 kHz higher – as intended after tuning. The third peak in between is a driven RF oscillation, generated by inducing an artificial GW with the piezo actuators, which validates the heterodyne detection scheme. The detectable signal is further enhanced if the frequency of the GW (or piezo excitation) matches the frequency difference of the fundamental mode and signal mode $f_{\text{drive}} + f_{\text{GW}} = f_{\text{signal}}$.

and enabled further development of the hard- and software. In addition, various features for a future search run were tested, including suppression of the drive mode on the detection branch of the data acquisition (DAQ) system and validation of the heterodyne detection scheme by inducing an artificial GW using piezo actuators (Fig. 2).

Proof-of-principle experiment

The goal of detecting high-frequency GWs using SRF cavities requires infrastructure and expertise that are available at only a few locations. For this reason, the project partners – among them some of the leading laboratories in this field – have joined forces to realise this experiment together. In particular, DESY’s comprehensive LLRF expertise plays a key role, complemented by its extensive experience in SRF cavity production and in the operation of large-scale cryogenic infrastructure.

The next steps include theory development to better understand key parameters of the cavity-LLRF-DAQ chain,



such as noise sources, and the GW-cavity interaction in order to propose an optimised cavity geometry and predict signal patterns [3, 4]. A first search run is envisioned within the next two years, with limited sensitivity over a large frequency range, to act as a proof-of-principle experiment. The experience gained will enable the design of a dedicated infrastructure, boosting this detection scheme to its full potential.

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References:

[1] R. Ballantini *et al.*, *Class. Quantum Grav.* **21**, 1241 (2004), DOI: 10.1088/0264-9381/21/5/127
[2] L. Fischer *et al.*, *Class. Quantum Grav.* **42**, 115015 (2025), DOI: 10.1088/1361-6382/add8da
[3] L. Fischer *et al.*, *Phys. Rev. D* **112**, 124085 (2025), DOI: 10.1103/h3nh-3hxx
[4] R. Löwenberg *et al.*, *Eur. Phys. J. C* **83**, 1153 (2023), DOI: 10.1140/epjc/s10052-023-12304-1

All forces working together for the LIMP

During the long installation and maintenance period (LIMP) of the European XFEL (see p. 46), maintenance work and numerous upgrades were carried out on the infrastructure in the underground tunnels and on the scientific instruments on the European XFEL campus. The joint efforts of all technical, scientific and administrative teams ensured that everything ran smoothly and successfully.

Picture: Evgeny Negodin, DESY



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➤ Memberships	79
➤ Publications	81

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E. Abassi <i>et al.</i> Heat load measurements of XFEL cryomodules using helium evaporation method. 1. 29th International Cryogenic Engineering Conference, International Cryogenic Materials Conference 2024, Geneva (Switzerland), 22 Jul 2024 - 26 Jul 2024. <i>IOP conference series / Materials science and engineering</i> , vol. 13271:012011, and PUBDB-2025-02024. Institute of Physics, London [u.a.] <i>doi: 10.1088/1757-899X/1327/1/012011.</i>
I. Agapov, A. Eichler and F. Mayet. AI for Light Source Applications at DESY. <i>Synchrotron radiation news</i> , 38(4):18, and PUBDB-2025-01707. <i>doi: 10.1080/08940886.2025.2539054.</i>
E. Allaria <i>et al.</i> Accurate measurements of slice electron beam parameters at the undulator in seeded Free Electron Lasers. <i>Journal of synchrotron radiation</i> , 32(1):72, and PUBDB-2024-05729. <i>doi: 10.1107/S1600577524011585.</i>
S. A. Antipov <i>et al.</i> Space charge effects in fourth-generation light sources: The PETRA IV and SOLEIL II cases. <i>Physical review accelerators and beams</i> , 28(2):024401, and PUBDB-2024-05709. <i>doi: 10.1103/PhysRevAccelBeams.28.024401.</i>
M. P. Backhouse <i>et al.</i> Spectral phase control for optimized ionization injection in laser wakefield acceleration. <i>Physical review accelerators and beams</i> , 28(12):121301, and PUBDB-2026-00038. <i>doi: 10.1103/9gjq-htzn.</i>
D. Bazyl <i>et al.</i> Multiphysics Analysis of Cryogenically Cooled Photocathode in a CW SRF Injector cavity. <i>Physical review accelerators and beams</i> , 29(1):013402, and PUBDB-2025-03653, arXiv:2508.11764. <i>doi: 10.1103/9jyv-hfxy.</i>
A. Biagioni <i>et al.</i> Technical status report on plasma components and systems in the context of EuPRAXIA. <i>Physics of plasmas</i> , 32(11):110501, and PUBDB-2025-05153. <i>doi: 10.1063/5.0286730.</i>
P. Biesterfeld <i>et al.</i> Post-compression of a Q-switched laser in a glass-rod multi-pass cell. <i>JPhys photonics</i> , 8(1):015013, and PUBDB-2025-05244. <i>doi: 10.1088/2515-7647/ae1fc4.</i>
A. Bikash Dey, O. Seeck and H. Reichert. Generic Rolling Access at PETRA III. <i>Synchrotron radiation news</i> , 38(5):20, and PUBDB-2026-00246. <i>doi: 10.1080/08940886.2025.2560290.</i>
H. Bolat <i>et al.</i> Development of cryogenically cooled permanent magnet undulators for PETRA IV. 1. 15th International Conference on Synchrotron Radiation Instrumentation, Hamburg (Germany), 26 Aug 2024 - 30 Aug 2024. <i>Journal of physics / Conference Series</i> , vol. 30101:012001, and PUBDB-2024-07660. IOP Publ., Bristol. <i>doi: 10.1088/1742-6596/3010/1/012001.</i>
L. Boukela, J. Branlard and A. Eichler. Exploring NAS for Anomaly Detection in Superconducting Cavities of Particle Accelerators. <i>Frontiers in physics</i> , 13:1553993, and PUBDB-2024-05389. <i>doi: 10.3389/fphy.2025.1553993.</i>
F. Brogren <i>et al.</i> Data-driven modeling of a laser-plasma accelerator-based x-ray source. <i>Physical review accelerators and beams</i> , 28(10):101302, and PUBDB-2025-05740. <i>doi: 10.1103/dnnw-lfn5.</i>
O. Chepurna <i>et al.</i> Polymeric nanoparticles with a thermoresponsive shell loaded with fluorescent molecules allow for thermally enhanced fluorescence imaging and singlet oxygen generation. <i>Nanoscale advances</i> , 7(7):1946, and PUBDB-2025-04406. <i>doi: 10.1039/D4NA00687A.</i>
J.-M. Christmann <i>et al.</i> Homogenized harmonic balance finite element method for non-linear eddy current simulations of fast corrector magnets. <i>Physical review accelerators and beams</i> , 28(10):104601, and PUBDB-2025-04135, arXiv:2503.19657. arXiv:2503.19657. <i>doi: 10.1103/9mnn-w7lj.</i>
E. C. Cortes Garcia, I. Agapov and W. Hillert. Design of a resonant slow extraction from low-emittance electron booster rings using transverse resonance island buckets. <i>Physical review accelerators and beams</i> , 28(1):011601, and PUBDB-2025-04356, arXiv:2404.02665. arXiv:2404.02665. <i>doi: 10.1103/PhysRevAccelBeams.28.011601.</i>
M. K. Czwalinna, J. Roeвер and J. Kral. Recent Upgrades Of Longitudinal Diagnostics At FLASH. 14th International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025. 2673-5350,670, and PUBDB-2025-03888. JACoW Publishing, Geneva. <i>doi: 10.18429/JACoW-IBIC2025-WEPCO23.</i>
I. V. Demydenko <i>et al.</i> X-ray transition radiation by high-energy electrons in a thin solid target placed in an external magnetic field. <i>Physical review accelerators and beams</i> , 28(12):124501, and PUBDB-2025-02478. <i>doi: 10.1103/dwpb-9dm7.</i>

G. K. Deyu *et al.*
Recent advances in atomic layer deposition of superconducting thin films: a review.
Materials Horizons, 12(15):5594, and PUBDB-2025-01180.
doi: 10.1039/D5MH00323G.

A. K. Dhillon *et al.*
Modelling two-phase He II flow for heat load limits in XFEL Cryomodules for CW operation.
Cryogenic Engineering Conference & International Cryogenic Materials Conference, Reno (USA), 18 May 2025 - 22 May 2025.
IOP conference series / Materials science and engineering, 1, and PUBDB-2025-02026.

P. Drobniak *et al.*
Development of a nonlinear plasma lens for achromatic beam transport.
2024 Advanced Accelerator Concepts workshop, Naperville, Illinois (USA), 21 Jul 2024 - 26 Jul 2024.
Nuclear instruments & methods in physics research / Section A, vol. 1072:170223, and PUBDB-2026-00377, arXiv:2411.00925.
Elsevier, [Amsterdam].
doi: 10.1016/j.nima.2025.170223.

A. Eichler *et al.*
ENHANCING QUENCH DETECTION IN SRF CAVITIES AT THE EUXFEL : TOWARDS MACHINE LEARNING APPROACHES AND PRACTICAL CHALLENGES.
16th International Particle Accelerator Conference, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
2673-5490, 3226, and PUBDB-2025-02163.
JACoW, Geneva.
doi: 10.18429/JACoW-IPAC25-THPS134.

T. Eichner *et al.*
Cryogenic 750-mJ Ti:Sapphire amplifier for laser plasma acceleration at 100-Hz repetition rate.
Optics letters, 50(16):4890, and PUBDB-2025-01146.
doi: 10.1364/OL.564062.

S. Elrajoubi *et al.*
Assessment of Power Quality in an Industrial Facility: A Case Study at DESY Hamburg.
IEEE open journal of instrumentation and measurement, 4:9000211, and PUBDB-2025-05145.
doi: 10.1109/OJIM.2025.3629874.

T. Faulwasser, A. Eichler and J. Berberich.
Data-driven and learning-based control – perspectives and prospects.
Automatisierungstechnik, 73(6):361, and PUBDB-2026-00574.
doi: 10.1515/auto-2025-0038.

E. Ferrari *et al.*
All hard X-ray Transient Grating Spectroscopy.
Communications Physics, 8(1):257, and PUBDB-2024-04923.
doi: 10.1038/s42005-025-02178-y.

L. Fischer *et al.*
First characterisation of the MAGO cavity, a superconducting RF detector for kHz–MHz gravitational waves.
Classical and quantum gravity, 42(11):115015, and PUBDB-2024-07014, FERMILAB-PUB-24-0819-SQMS-TD. DESY-24-181. arXiv:2411.18346.
doi: 10.1088/1361-6382/add8da.

K. Floettmann.
Open Resonator Model for Attenuated Total Reflection Dips.
Optics communications, 586:131868, and PUBDB-2025-00347.
doi: 10.1016/j.optcom.2025.131868.

B. Foster *et al.*
Proceedings of the Erice Workshop: A new baseline for the hybrid, asymmetric, linear Higgs factory HALHF.
Physics open, 23:100261, and PUBDB-2025-05374, arXiv:2501.11072.
doi: 10.1016/j.physo.2025.100261.

E. Genthe *et al.*
Seismic Noise Contributions to EuXFEL Bunch Arrival Time Jitter from Ocean-Generated Microseism.
High power laser science and engineering, 13:e52, and PUBDB-2024-05851.
doi: 10.1017/hpl.2025.40.

C. Hespe *et al.*
Data-Driven Feedback Optimization for Particle Accelerator Application.
Automatisierungstechnik, 73(6):429, and PUBDB-2024-07329.
doi: 10.1515/auto-2024-0170.

A. Hoffmann *et al.*
Efficient Generation of Transversely and Longitudinally Truncated Chirped Gaussian Laser Pulses for Application in High-Brightness Photoinjectors.
Photonics, 12(05):460, and PUBDB-2025-01202.
doi: 10.3390/photonics12050460.

A. Huebl *et al.*
Towards Differentiable Beam Dynamics Modeling in BLAST/ImpactX.
North American Particle Accelerator Conference , Sacramento, CA (USA), 10 Aug 2025 - 15 Aug 2025.
JACoW NAPAC2025 (2026) TUP101, 614, and PUBDB-2025-03643.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-NAPAC2025-TUP101.

S. M. Jaster-Merz *et al.*
Experimental demonstration of a tomographic five-dimensional phase-space reconstruction.
Physical review research, 7(4):043211, and PUBDB-2024-08048.
doi: 10.1103/m4wh-mhdm.

J. Kaiser, A. Lauscher and A. Eichler.
Large language models for human-machine collaborative particle accelerator tuning through natural language.
Science advances, 11(1):eadr4173, and PUBDB-2024-06977.
doi: 10.1126/sciadv.adr4173.

J. Kang *et al.*
Imaging of dynamic processes in materials with a laser-wakefield accelerator.
Physical review applied, 24(6):064013, and PUBDB-2026-00186.
doi: 10.1103/jzzn-bsy8.

P. Karataev *et al.*
Quasi-continuous X-ray generation in LiTaO3-based pyroelectric accelerator driven by periodically varying temperature.
Scientific reports, 15(1):31209, and PUBDB-2025-04824.
doi: 10.1038/s41598-025-15436-4.

C. Kittel *et al.*
Enhancing hard X-ray beamline performance at SwissFEL through spontaneous radiation measurements.
Journal of synchrotron radiation, 33(1):32, and PUBDB-2025-03903.
doi: 10.1107/S1600577525010227.

V. Kocharyan *et al.*
Observation of X-ray transition radiation from a relativistic electron passing a stack of plates.
Channeling 2024, Riccione (Italy), 8 Sep 2024 - 13 Sep 2024.
Nuclear instruments & methods in physics research / Section A, vol. 1075:170418, and PUBDB-2025-00212.
Elsevier, [Amsterdam].
doi: 10.1016/j.nima.2025.170418.

J. Kral *et al.*
High-performance bunch arrival time monitors with fs precision at DESY.
International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025.
2673-5350, 832, and PUBDB-2025-03652.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IBIC2025-THBC01.

M. Krasilnikov *et al.*
First high peak and average power single-pass THz free-electron laser in operation.
Physical review accelerators and beams, 28(3):030701, and PUBDB-2025-01236.
doi: 10.1103/PhysRevAccelBeams.28.030701.

V. Lang *et al.*
Know your footprint – Evaluation of the professional carbon footprint for individual researchers in highenergy physics and related fields.
npj climate action, 4(1):28, and PUBDB-2025-00762, arXiv:2403.03308.
doi: 10.1038/s44168-025-00232-7.

X. Li *et al.*
Demonstration of ultra-high dose rate electron irradiation at FLASHlab@PITZ and new capabilities in the future.
Physics in medicine and biology, 70(5):055010, and PUBDB-2024-06215.
doi: 10.1088/1361-6560/adb276.

S. Liu *et al.*
Updates on the Hard X-ray Self-seeding at the European XFEL.
Synchrotron radiation news, 38(2):11, and PUBDB-2025-00926.
doi: 10.1080/08940886.2025.2472607.

T. Long *et al.*
Control of bandwidth and signal-to-noise ratio for hard X-ray self-seeded free-electron lasers.
Physical review applied, 23(4):044038, and PUBDB-2024-05447.
doi: 10.1103/PhysRevApplied.23.044038.

F. Ludwig *et al.*
RF controls based on carrier suppression detection with attosecond resolution.
Physical review accelerators and beams, 28(7):072803, and PUBDB-2024-06331.
doi: 10.1103/jhc3-dtzw.

F. Mayet *et al.*
Toward particle accelerator machine state embeddings as a modality for large language models.
International Conference on Accelerator and Large Experimental Physics Control Systems, Chicago (USA), 20 Sep 2025 - 26 Sep 2025.
2226-0358, 1233, and PUBDB-2025-03902.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-ICALEPCS2025-WEPD082.

S. M. Mewes *et al.*
Characterization of discharge capillaries via benchmarked hydrodynamic plasma simulations.
Physical review research, 7(4):043193, and PUBDB-2025-01686.
doi: 10.1103/kv2z-ps8h.

M. Mohammadi Bidhendi *et al.*
Characterization of free-electron laser third harmonic radiation at FLASH.
Optics express, 33(5):10981, and PUBDB-2024-07443.
doi: 10.1364/OE.551587.

M. Pavelka *et al.*
Femtosecond charge and spin dynamics in a Co₅₀Pt₅₀ alloy.
Structural dynamics, 12(2):024303, and PUBDB-2025-00531.
doi: 10.1063/4.0000297.

A. Penirschke *et al.*
Ultrafast THz detection and enhanced Electro-Optical timing for longitudinal beam diagnostics at Free Electron Lasers.
North American Particle Accelerator Conference, Sacramento, CA (USA), 10 Aug 2025 - 15 Aug 2025.
2673-7000, 910, and PUBDB-2025-04333.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-NAPAC2025-THAN03.

P. Putek *et al.*
Uncertainty and worst-case expectation analysis for multiphysics QPR simulations.
Superconductor science and technology, 38(2):025002, and PUBDB-2024-07252.
doi: 10.1088/1361-6668/ad9a0d.

J. Rönsch-Schulenburg *et al.*
Operation of the variable polarization undulator on the third harmonic of a SASE FEL.
X-Ray Free-Electron Lasers: Advances in Source Development and Instrumentation VII, Prague (Czech Republic), 7 Apr 2025 - 11 Apr 2025.
Proceedings of SPIE, vol. 13536:1353604, and PUBDB-2025-05846.
SPIE, Bellingham, Wash.
doi: 10.1117/12.3058405.

D. Samoilenko *et al.*
Effects of boundary conditions on Coherent Synchrotron Radiation in Echo-Enabled Harmonic Generation.
Physical review accelerators and beams, 28(4):040702, and PUBDB-2024-01027.
doi: 10.1103/PhysRevAccelBeams.28.040702.

B. E. J. Scheible *et al.*
Concepts For Beam Diagnostics Based On Planar Pickups On A Printed Circuit Board.
14th International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025.
2673-5350,821, and PUBDB-2025-03785.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IBIC2025-WEPMO36.

A. Schoenberg *et al.*
Compact, folded multi-pass cells for energy scaling of post-compression.
Photonics research, 13(3):761, and PUBDB-2024-05748.
doi: 10.1364/PRJ.540977.

A. Shchagin *et al.*
Doppler effect in vacuum, homogeneous, and periodical media in X-ray range.
Nuclear instruments & methods in physics research / Section A, A(1072):170235, and PUBDB-2024-07628.
doi: 10.1016/j.nima.2025.170235.

B. Steffen *et al.*
Compact electro-optical bunch length detector: from an expert device to an operator tool.
International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025.
2673-5350,673, and PUBDB-2025-03773.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IBIC2025-WEPCO24.

E. Svirplys *et al.*
Plasma lens for focusing attosecond pulses.
Nature photonics, -:-, and PUBDB-2025-01324.
doi: 10.1038/s41566-025-01794-y.

A. Trebushinin *et al.*
First Observation of Synchrotron Radiation Spikes for Transverse Electron Beam Size Measurements at a Free-Electron Laser.
Physical review letters, 135(21):215001, and PUBDB-2026-00277.
doi: 10.1103/z89g-f7j6.

A. Trebushinin *et al.*
Noninterferometric method for transverse electron beam size diagnostic with synchrotron radiation at a free-electron laser.
Physical review accelerators and beams, 28(11):112801, and PUBDB-2025-05674.
doi: 10.1103/31gl-qyk7.

M. Urbański *et al.*
An Upgrade of Radio Frequency Reference Generation and Distribution Modules for FLASH2020+.
Electronics, 14(1):173, and PUBDB-2025-00488.
doi: 10.3390/electronics14010173.

R. Wanzenberg *et al.*
PETRA III Operational Performance and Availability in 2023.
1. 15th International Conference on Synchrotron Radiation Instrumentation, Hamburg (Germany), 26 Aug 2024 - 30 Aug 2024.
Journal of physics / Conference Series, vol. 30101:012030, and PUBDB-2024-06271.
IOP Publ., Bristol.
doi: 10.1088/1742-6596/3010/1/012030.

R. Watt *et al.*
Bounding elastic photon-photon scattering at $\sqrt{s} \approx 1$ MeV using a laser-plasma platform.
Physics letters / B, 861:139247, and PUBDB-2024-00751, arXiv:2407.12915. arXiv:2407.12915.
doi: 10.1016/j.physletb.2025.139247.

M. Wenskat *et al.*
Thermal transmittance measurements of niobium at cryogenic temperatures.
Physica / C, 632:1354694, and PUBDB-2024-06669.
doi: 10.1016/j.physc.2025.1354694.

P. V. Winkler *et al.*
Active Energy Compression of a Laser-Plasma Electron Beam.
Nature, 640(8060):907, and PUBDB-2024-07200.
doi: 10.1038/s41586-025-08772-y.

Z. Yin *et al.*
A Green and Efficient Electrocatalytic Route for the Highly-Selective Oxidation of C–H Bonds in Aromatics over 1D Co₃O₄-Based Nanoarrays.
Angewandte Chemie, 137(3):e202415044, and PUBDB-2025-01990.
doi: 10.1002/ange.202415044.

Z. Yin *et al.*
A Green and Efficient Electrocatalytic Route for the Highly-Selective Oxidation of C–H Bonds in Aromatics over 1D Co₃O₄-Based Nanoarrays.
Angewandte Chemie / International edition, 64(3):e202415044, and PUBDB-2024-05980.
doi: 10.1002/anie.202415044.

A. Zaidman *et al.*
Influence of an Al₂O₃ Capping Layer on the Thermal Reduction of the NativeNiobium Oxide: An In situ X-ray Reflectivity Study.
Physical review materials, 9(9):094806, and PUBDB-2025-02182.
doi: 10.1103/48mp-wypj.

S. Zeeshan *et al.*
Beam dynamics optimization for a higher-brightness photo injector with various photocathode laser pulse shape.
Journal of physics / Conference Series, 3094(1):012021, and PUBDB-2025-04550.
doi: 10.1088/1742-6596/3094/1/012021.

Preprints and Internal Reports

E. Adli *et al.*
HALHF: a hybrid, asymmetric, linear Higgs factory using plasma- and RF-based acceleration. Backup Document.
PUBDB-2025-05059, arXiv:2503.23489.
doi: 10.3204/PUBDB-2025-05059.

D. Bazyl *et al.*
Multiphysics Analysis of Cryogenically Cooled Photocathode in a CW SRF Injector cavity.
PUBDB-2026-00225, arXiv:2508.11764.
doi: 10.3204/PUBDB-2026-00225.

J. de Blas *et al.*
Physics Briefing Book: Input for the 2026 update of the European Strategy for Particle Physics.
PUBDB-2025-05379, arXiv:2511.03883. CERN-ESU-2025-001.
doi: 10.3204/PUBDB-2025-05379.

J.-M. Christmann *et al.*
Homogenized harmonic balance finite element method for non-linear eddy current simulations of fast corrector magnets.
PUBDB-2025-04354, arXiv:2503.19657.

E. C. Cortés García, I. V. Agapov and W. Hillert.
Design of a resonant slow extraction from low-emittance electron booster rings using transverse resonance island buckets.
PUBDB-2025-04692, arXiv:2404.02665.
doi: 10.3204/PUBDB-2025-04692.

B. Cros *et al.*
Contribution of ALEGRO to the Update of the European Strategy on Particle Physics.
PUBDB-2025-05368, arXiv:2504.01434.
doi: 10.3204/PUBDB-2025-05368.

P. Drobniak *et al.*
Development of a nonlinear plasma lens for achromatic beam transport.
PUBDB-2026-00460, arXiv:2411.00925.

G. Dugan *et al.*
ILC250 Cost Update – 2024.
PUBDB-2025-01790, arXiv:2506.00353. IDT-EB2025-001-Supplement.
doi: 10.3204/PUBDB-2025-01790.

B. Foster *et al.*
Proceedings of the Erice workshop: A new baseline for the hybrid, asymmetric, linear Higgs factory HALHF.
PUBDB-2026-00145, arXiv:2501.11072.
doi: 10.3204/PUBDB-2026-00145.

S. Gessner *et al.*
Design Initiative for a 10 TeV pCM Wakefield Collider.
PUBDB-2025-05371, arXiv:2503.20214. FERMILAB-CONF-25-0214-CSAID.
doi: 10.3204/PUBDB-2025-05371.

HALHF Collaboration.
HALHF: a hybrid, asymmetric, linear Higgs factory using plasma- and RF-based acceleration.
PUBDB-2025-05373, arXiv:2503.19880.
doi: 10.3204/PUBDB-2025-05373.

ICFA ILC International Development Collaboration and ILC-Japan Collaboration.
Status of the International Linear Collider.
PUBDB-2025-05058, arXiv:2505.11292. FERMILAB-PUB-25-0345-TD.
doi: 10.3204/PUBDB-2025-05058.

M. Ivanyan *et al.*
Helical Motion of a Particle in a Multilayer Cylindrical Waveguide.
PUBDB-2026-00347, arXiv:2501.12802.
doi: 10.3204/PUBDB-2026-00347.

D. Kalvik *et al.*
Ion-motion simulations of a plasma-wakefield experiment at FLASHForward.
PUBDB-2026-00147, arXiv:2505.24299.

M. Krasilnikov.
GUN5.1 REPORT Conditioning and operation at PITZ 2021-2024.
PUBDB-2025-01054.

V. Lang *et al.*
Know your footprint - Evaluation of the professional carbon footprint for individual researchers in high energy physics and related fields.
PUBDB-2025-00905, arXiv:2403.03308.
doi: 10.3204/PUBDB-2025-00905.

C. A. Lindstrøm *et al.*
Updated baseline design for HALHF: the hybrid, asymmetric, linear Higgs factory.
PUBDB-2025-05366, arXiv:2505.21654.
doi: 10.18429/JACoW-IPAC25-MOCD1.

R. Watt *et al.*
Bounding elastic photon-photon scattering at $\sqrt{s} \approx 1$ MeV using a laser-plasma platform.
PUBDB-2025-00404, arXiv:2407.12915.

Books

I. Agapov *et al.*
The Plasma Injector for PETRA IV: Enabling Plasma Accelerators for Next-generation Light Sources. Conceptual Design Report.
Deutsches Elektronen-Synchrotron DESY, Hamburg.
doi: 10.3204/PUBDB-2024-06078.

Conference Contributions

IBIC2025

B. Stacey *et al.*
Smith-Purcell and Transition Radiation Based Charged Particle Beam Diagnostics for the Femtosecond-Range.
14th International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025.
PUBDB-2025-03944.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IBIC2025-WEPMO03.

S. Stokov *et al.*
First measurements of a prototype stripline BPM for PETRA IV comparison with simulation.
14th International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025.
PUBDB-2026-00195.
JACoW Publishin, Geneva, Switzerland.
doi: 10.18429/JACoW-IBIC2025-WEPCO26.

IPAC’25

M. Grecki *et al.*
Optimization of Piezo Operation for Superconducting TESLA Cavities at EuXFEL.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-02270.
JACoW Publishing, [Geneva].
doi: 10.18429/JACoW-IPAC2025-THPS040.

M. Gross *et al.*
Commissioning of the new FLASHlab@PITZ Beamline Extension.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-04112.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-MOPM077.

D. Ilia *et al.*
Novel photoinjector laser providing advanced pulse shaping for FLASH and EuXFEL.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01743.
JACoW Publishing, [Geneva].
doi: 10.18429/JACoW-IPAC2025-THPB027.

D. Kalvik *et al.*
Ion-motion simulations of a plasma-wakefield experiment at FLASHForward.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-05731, arXiv:2505.24299.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-TUPS013.

T. Long *et al.*
Twin-bunch modelling in linear accelerators for plasma wake-field acceleration.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2024-07478.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-TUPM089.

K. Peetermans, I. Zagorodnov and F. Lemery.
Cherenkov waveguide design for THz production at the EuXFEL.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 2 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01754.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-TUPM032.

K. C. A. Peetermans *et al.*
Courant-Snyder formalism for modeling, optimizing and simulating broadband THz radiation transport.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 2 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01765.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-TUPM031.

K. C. A. Peetermans *et al.*
Optimizing Cherenkov waveguide seeding for THz SASE FELs towards stable, few-cycle pulses.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 2 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01767.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-MOPB106.

K. C. A. Peetermans *et al.*
Simulation and optimization of a sub-THz Cherenkov FEL at AREAL.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 2 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01763.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-MOPB105.

B. E. J. Scheible *et al.*
Substrate material studies for PCB-based electro-optical bunch arrival-time monitors for XFELs.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01653.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-THPS107.

S. Schulz *et al.*
Latest achievements in femtosecond synchronization of large scale facilities.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-05472.
JACoW Publishing, Geneva.
doi: 10.18429/JACOW-IPAC2025-FRZD1.

M. Vogt *et al.*
Flash status 2024 - FEL operation for users and upgrade shutdown.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2026-00816.
JACoW Publishing, Geneva.
doi: 10.18429/JACOW-IPAC2025-MOPB019.

J. Wernsmann, F. Giesteira and F. Lemery.
Development and laboratory validation of a precise alignment setup for electron beam-based THz radiation generation at European XFEL.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipeh (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01769.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-THPB012.

J. Wernsmann *et al.*
Design, fabrication, and characterization of 3D-printed photonic crystals for THz filtering applications in particle accelerators.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipeh (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01768.
JACoW Publishing, Geneva.
doi: 10.18429/JACoW-IPAC2025-THPB011.

S. Zeeshan *et al.*
Beam dynamics optimization in high-brightness Photo Injector with various photocathode laser pulse shapes.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-01201.
JACoW Publishing, Bristol.
doi: 10.18429/JACoW-IPAC2025-TUPS019.

CLEO/Europe-EQEC 2025

C. Braun *et al.*
A Simple 1 mJ Ti:Sapphire Booster Amplifier for the KALDERA plasma Acceleration Drive Laser at 1 kHz.
2025 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich (Germany), 23 Jun 2025 - 27 Jun 2025.
PUBDB-2025-05003.
IEEE, [Piscataway, NJ].
doi: 10.1109/CLEO/Europe-EQEC65582.2025.11111522.

T. Eichner *et al.*
A 100Hz Ti:Sapphire Amplifier Delivering 700mJ Pulses for High Energy Laser Plasma Acceleration.
2025 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich (Germany), 23 Jun 2025 - 27 Jun 2025.
PUBDB-2025-04999.
IEEE, [Piscataway, NJ].
doi: 10.1109/CLEO/Europe-EQEC65582.2025.11109709.

E. Ferrari.
Twin Echo-Enabled Harmonic Generation for Enhanced Coherent Bunching at Short Wavelength.
2025 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich (Germany), 23 Jun 2025 - 27 Jun 2025.
PUBDB-2025-04987.
IEEE, [Piscataway, NJ].
doi: 10.1109/CLEO/Europe-EQEC65582.2025.11109497.

T. Hülsenbusch *et al.*
White-Light Seeded, Collinear OPCPA Front-End for LPA Drive Lasers at 800 nm.
2025 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich (Germany), 23 Jun 2025 - 27 Jun 2025.
PUBDB-2025-04982.
IEEE, [Piscataway, NJ].
doi: 10.1109/CLEO/Europe-EQEC65582.2025.11111284.

D. Ilia *et al.*
Temporal Shaping of UV Picosecond Pulses for Photoinjectors.
2025 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich (Germany), 23 Jun 2025 - 27 Jun 2025.
PUBDB-2025-01746.
IEEE, [Piscataway, NJ].
doi: 10.1109/CLEO/Europe-EQEC65582.2025.11111289.

G. Palmer *et al.*
The KALDERA Ti:Sapphire Drive-Laser for Laser Plasma Acceleration at High Repetition Rates.
2025 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC), Munich (Germany), 23 Jun 2025 - 27 Jun 2025.
PUBDB-2025-05004.
IEEE, [Piscataway, NJ].
doi: 10.1109/CLEO/Europe-EQEC65582.2025.11109123.

The 50th International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz 2025, Espoo/Helsinki, Finland, 17 Aug 2025 - 22 Aug 2025

N. Aftab *et al.*
Overview of THz diagnostics at PITZ.
The 50th International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz 2025, Espoo/Helsinki, Finland, 17 Aug 2025 - 22 Aug 2025, Helsinki (Finland), 17 Aug 2025 - 22 Aug 2025.
PUBDB-2025-04659.
IEEE, New York, NY.
doi: 10.1109/IRMMW-THz61557.2025.11320051.

M. Krasilnikov *et al.*
High Power Single Pass THz FEL in Operation at PITZ.
The 50th International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz 2025, Espoo/Helsinki, Finland, 17 Aug 2025 - 22 Aug 2025, Espoo/Helsinki (Finland), 17 Aug 2025 - 22 Aug 2025.
PUBDB-2026-00311.
IEEE.
doi: 10.1109/IRMMW-THz61557.2025.11319917.

Other Conference Contributions

Q. Demazeux *et al.*
Single-Shot electro-optic detection of broadband THz at EuXFEL and FLASH using diversity scheme with advanced reconstruction algorithms.
50th International Conference on Infrared, Millimeter, and Terahertz Waves , Helsinki (Finland), 17 Aug 2025 - 22 Aug 2025.
PUBDB-2026-00373.
IEEE.
doi: 10.1109/IRMMW-THz61557.2025.11319759.

B. Dursun *et al.*
PETRA-IV FOFB System Integration Test Setup.
20th International Conference on Accelerator and Large Experimental Physics Control Systems, Chicago (USA), 20 Sep 2025 - 26 Sep 2025.
PUBDB-2025-05839.
JACoW Publishing, [Geneva].
doi: 10.18429/JACOW-ICALEPCS2025-THCG005.

M. Ivanyan *et al.*
Helical Motion of a Particle in a Multilayer Cylindrical Waveguide.
2871705. 2025 Photonics & Electromagnetics Research Symposium - Spring, Abu Dhabi (United Arab Emirates), 4 May 2025 - 8 May 2025.
PUBDB-2026-00341, arXiv:2501.12802.
IEEE.
doi: 10.1109/PIERS-Spring66516.2025.11276786.

D. Schwickert *et al.*
Arrival Time Analysis of the Pump-Probe Laser at the XPB Experiment at the EuXFEL.
Advanced Solid-State Laser Conference , Prague (Czech Republic), 19 Oct 2025 - 24 Oct 2025.
PUBDB-2025-01835.

T. Warnecke and G. Lichtenberg.
Approach for the Mode Switching Problem in Piecewise Smooth Implicit Multilinear IVPs.
15th International Conference on Simulation, Modeling Methodologies, Technologies and Applications, Bilbao (Spain), 11 Jun 2025 - 13 Jun 2025.
PUBDB-2026-00536.
SCITEPRESS - Science and Technology Publications.
doi: 10.5220/0013578200003970.

Conference Presentations

13th MT ARD ST3 Meeting 2025 at DESY in Zeuthen, Zeuthen, Germany, 25 Jun 2025 - 27 Jun 2025

N. Aftab *et al.*
Overview of THz Diagnostics at PITZ.
13th MT ARD ST3 Meeting 2025 at DESY in Zeuthen, Zeuthen, Germany, 25 Jun 2025 - 27 Jun 2025, Zeuthen (Germany), 25 Jun 2025 - 27 Jun 2025.
PUBDB-2026-00309.

S. Zeeshan *et al.*
Beam Dynamics Optimization for a High-brightness Photo Injector with various Photocathode Laser Pulse Shapes.
13th MT ARD ST3 Meeting 2025 at DESY in Zeuthen, Zeuthen, Germany, 25 Jun 2025 - 27 Jun 2025, Zeuthen (Germany), 25 Jun 2025 - 27 Jun 2025.
PUBDB-2025-04661.

IPAC25

D. Kalvik *et al.*
Ion-motion simulations of a plasma-wakefield experiment at FLASHForward.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-05730.

T. Long *et al.*
Twin-bunch modelling in linear accelerators for plasma wake-field acceleration.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-05718.

S. Zeeshan *et al.*
Beam Dynamics Optimization for a High-brightness PhotoInjector with various Photocathode Laser Pulse Shapes.
16th International Particle Accelerator Conference, IPAC25, Taipei, DESY, Taiwan, 1 Jun 2025 - 6 Jun 2025, Taipei (Taiwan), 1 Jun 2025 - 6 Jun 2025.
PUBDB-2025-04552.

SRF2025

S. Barbanotti *et al.*
The Path to High Duty Cycle at EuXFEL - Cryomodule developments.
22nd International Conference on RF Superconductivity, Tokio (Japan), 21 Sep 2025 - 26 Sep 2025.
PUBDB-2025-04425.

V. Fogel *et al.*
Optimization of some operating parameters to increase the beam delivery time at the European XFEL.
22nd International Conference on RF Superconductivity, Tokio (Japan), 21 Sep 2025 - 26 Sep 2025.
PUBDB-2025-01385.

S. M. Jaster-Merz *et al.*
Cold integration of the DESY CW L-band SRF injector cavity with copper photocathode.
22nd International Conference on RF Superconductivity, Tokio (Japan), 21 Sep 2025 - 26 Sep 2025.
PUBDB-2025-05221.

EAAC

J. Beinortaite *et al.*
Long-duration ionisation effects in beam-driven plasma-wakefield accelerators.
7th European Advanced Accelerator Conference, Elba (Italy), 21 Sep 2025 - 27 Sep 2025.
PUBDB-2025-05729.

J. H. Björklund Svensson *et al.*
Slice Emittance Preservation and Focus Control in a Passive Plasma Lens.
7th European Advanced Accelerator Conference, Elba (Italy), 21 Sep 2025 - 27 Sep 2025.
PUBDB-2025-05728.

L. A. Boulton *et al.*
Advanced Controls and Machine Learning at FLASHForward.
7th European Advanced Accelerator Conference, Elba (Italy), 21 Sep 2025 - 27 Sep 2025.
PUBDB-2025-05726.

J. P. J. Diaz Pacheco *et al.*
Temperature diagnostics for high-repetition-rate plasma accelerator sources.
7th European Advanced Accelerator Conference, Elba (Italy), 21 Sep 2025 - 27 Sep 2025.
PUBDB-2025-05727.

J. C. Wood *et al.*
Latest Results from the FLASHForward Experiment.
7th European Advanced Accelerator Conference, Elba (Italy), 21 Sep 2025 - 27 Sep 2025.
PUBDB-2025-05724.

J. C. Wood *et al.*
Physics Considerations for a Plasma Booster Stage for the European XFEL.
7th European Advanced Accelerator Conference, Elba (Italy), 21 Sep 2025 - 27 Sep 2025.
PUBDB-2025-05725.

DGMP

A. Grebinyk.
Von der Beschleunigerphysik zur biomedizinischen Anwendung: Aufbau des Biolabors und zelluläre Experimente am FLASHlab@PITZ.
DGMP, Berlin (Germany), 24 Sep 2025 - 27 Sep 2025.
PUBDB-2026-00237.

Y. Komar.
Advancing FLASH-Radiotherapy: PEGylated Nanoliposomes for Tumor Radiosensitization and Imaging at FLASHlab@PITZ.
DGMP, Berlin (Germany), 24 Sep 2025 - 27 Sep 2025.
PUBDB-2026-00239.

E. Tarakci.
Method Validation to Evaluate the Effects of X-Ray Radiation on Zebrafish Embryo Development.
DGMP, Berlin (Germany), 24 Sep 2025 - 27 Sep 2025.
PUBDB-2026-00238.

DPG Spring Meeting 2025

P. Burghart *et al.*
A virtual spectral diagnostic for plasma accelerated bunches at FLASHForward.
DPG Spring Meeting 2025, Göttingen (Germany), 31 Mar 2025 - 4 Apr 2025.
PUBDB-2025-05713.

J. P. J. Diaz Pacheco *et al.*
Considerations for high repetition rate plasma accelerator sources - Advanced diagnostics for MHz-repetition-rate plasma accelerator sources.
DPG Spring Meeting 2025, Göttingen (Germany), 31 Mar 2025 - 4 Apr 2025.
PUBDB-2025-05716.

FRPT 2025

M. Gross *et al.*
Commissioning of the new FLASHlab@PITZ Beamline Extension: First Results.
FLASH RADIOTHERAPY and PARTICLE THERAPY CONFERENCE 2025, FRPT 2025, Prague, Czech Republic, 10 Dec 2025 - 12 Dec 2025, Prague (Czech Republic), 10 Dec 2025 - 12 Dec 2025.
PUBDB-2025-05665.

Y. Komar.
In vitro radiobiological effects of ultra-high dose rate irradiation at FLASHlab@PITZ.
FLASH RADIOTHERAPY and PARTICLE THERAPY CONFERENCE 2025, FRPT 2025, Prague, Czech Republic, 10 Dec 2025 - 12 Dec 2025, prague (Czech Republic), 10 Dec 2025 - 12 Dec 2025.
PUBDB-2026-00242.

FLASH Workshop 2025: The Role of Oxygen in FLASH Radiation Therapy

E. Tarakci.
Primary work with zebrafish embryos to enable comparative UHDR electron radiation studies at FLASHlab@PITZ.
FLASH Workshop 2025: The Role of Oxygen in FLASH Radiation Therapy, Heidelberg (Germany), 1 Jul 2025 - 3 Jul 2025. PUBDB-2025-02381.

E. Tarakci *et al.*
BioLab at FLASHlab@PITZ for Preclinical Research: Established Zebrafish (Danio Rerio) Husbandry.
FLASH Workshop 2025: The Role of Oxygen in FLASH Radiation Therapy, Heidelberg (Germany), 1 Jul 2025 - 3 Jul 2025. PUBDB-2025-02380.

Other Conference Presentations

N. Aftab *et al.*
Overview of THz diagnostics at PITZ.
IRMMW-THz 2025, Helsinki (Finland), 17 Aug 2025 - 22 Aug 2025. PUBDB-2025-04660.

L. A. Boulton *et al.*
Advanced Controls and Machine Learning at FLASHForward.
LPA Special Workshop on Intelligent Systems 2025, Oxford (UK), 13 Jan 2025 - 16 Jan 2025. PUBDB-2025-05711.

J.-M. Christmann *et al.*
Harmonic Balance Finite Element Method Combined With a Homogenization of Laminated Yokes.
25th International Conference on the Computation of Electromagnetic Fields, Naples (Italy), 22 Jun 2025 - 26 Jun 2025. PUBDB-2025-01500.

B. Dursun *et al.*
PETRA-IV FOFB System Integration Test Setup.
20th International Conference on Accelerator and Large Experimental Physics Control Systems, Chicago (USA), 20 Sep 2025 - 26 Sep 2025. PUBDB-2025-05840.

A. Grebinyk *et al.*
FLASHlab@PITZ: Prooxidant and apoptotic effects of ultrahigh dose rate electron irradiation in vitro.
Workshop & Symposium: Tumor Immunology meets Oncology XIX, Brandenburg (Germany), 22 May 2025 - 24 May 2025. PUBDB-2025-01740.

M. Huck *et al.*
Capillary discharge plasma sources and diagnostics for plasma wakefield acceleration at FLASHForward, DESY.
6th European Conference on Plasma Diagnostics, Prague (Czech Republic), 7 Apr 2025 - 10 Apr 2025. PUBDB-2025-05720.

D. Ilia *et al.*
Differentiable Models for Control of Complex Physical Systems: A Case Study in Laser Pulse Shaping.
Machine Learning and the Physical Sciences Workshop, NeurIPS 2025, San Diego (USA), 1 Dec 2025 - 7 Dec 2025. PUBDB-2025-05225.

D. Ilia *et al.*
Machine Learning driven beam emittance optimization at EuXFEL.
5th ICFA Beam Dynamics Mini-Workshop on Machine Learning for Particle Accelerators, CERN (Switzerland), 8 Apr 2025 - 11 Apr 2025. PUBDB-2026-00809.

M. Krasilnikov.
High Power Single Pass THz FEL in Operation at PITZ.
The 50th International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz 2025, Espoo/Helsinki, Finland, 17 Aug 2025 - 22 Aug 2025, Espoo/Helsinki (Finland), 17 Aug 2025 - 22 Aug 2025. PUBDB-2026-00312.

W. Leemans.
Accelerator Activities at DESY.
BNL Colloquium, BNL, Brookhaven (USA), 28 Aug 2025. PUBDB-2026-01146.

W. Leemans.
25th Anniversary of the First Lasing at TTF (now FLASH) – International Symposium – Welcome.
25th Anniversary of the First Lasing at TTF (now FLASH) – International Symposium, Hamburg (Germany), 17 Nov 2025 - 18 Nov 2025. PUBDB-2026-01145.

W. Leemans.
Hamburg: A unique place for Accelerators, Photonics and Entrepreneurship.
Kick-off Workshop for HICAPE, Hamburg (Germany), 5 Dec 2025. PUBDB-2026-01147.

W. Leemans.
EPACE Kick-off Meeting – Welcome.
EPACE Kick-off Meeting, Hamburg (Germany), 15 Dec 2025 - 15 Dec 2025. PUBDB-2026-01148.

X. Li *et al.*
Commissioning of FLASHlab@PITZ – The R&D platform for electron FLASH radiation therapy.
DGMP 2025, Berlin (Germany), 24 Sep 2025 - 27 Sep 2025. PUBDB-2026-00177.

X. Li *et al.*
Generating Homogeneous And Spatially Fractionated Radiation Fields By Electron Beam Scanning.
5th FLASH Radiotherapy & Particle Therapy, Prague (Czech Republic), 10 Dec 2025 - 12 Dec 2025. PUBDB-2026-00178.

X. Li *et al.*
Generation of micrometer electron beams from FLASHlab@PITZ.
3rd International Particle Minibeam Radiotherapy (PMBT) Workshop, Teddington (UK), 17 Mar 2025 - 19 Mar 2025. PUBDB-2025-01322.

X. Li *et al.*
PITZ facility overview.
MTARD ST3 Meeting 2025, Zeuthen (Germany), 25 Jun 2025 - 27 Jun 2025. PUBDB-2026-00181.

X. Li *et al.*
The new beamline and biolab at FLASHlab@PITZ.
VHEE 2025, Daresbury (UK), 15 Sep 2025 - 17 Sep 2025. PUBDB-2026-00179.

T. Long.
Bandwidth and signal-to-noise ratio control for hard x-ray self-seeded free-electron lasers.
1st HXRSS workshop, Pohang (South Korea), 15 Oct 2025 - 17 Oct 2025. PUBDB-2025-05719.

J. Miericke *et al.*
System-on-Chip-basierte Magnetstromregelung in einem MicroTCA-System.
4. KAI Workshop zur Intensivierung der Zusammenarbeit, Hamburg (Germany), 5 May 2025 - 5 May 2025. PUBDB-2025-01687.

S. H. Mirza.
Stable Orbits, Brighter Beams:Understanding and Controlling Orbit Stability in 4th Generation Synchrotron Light Sources.
International Beam Instrumentation Conference, Liverpool (UK), 7 Sep 2025 - 11 Sep 2025. PUBDB-2025-05032.

F. Mueller.
A New RF Spring Mechanism ... for Exchangeable Cathodes in High Brightness Gunsat DESY.
13th International Conference Mechanics Engineering Design Synchrotron Radiation Equipment Instrumentation, Lund (Sweden), 15 Sep 2025 - 19 Sep 2025. PUBDB-2025-04069.

S. Pfeiffer.
Status of the design and simulations for the FOFB of PETRA IV.
I.FAST Workshop 2025 on the Stability of Storage Ring Based Light Sources, Karlsruhe (Germany), 17 Mar 2025 - 21 Mar 2025. PUBDB-2025-05024.

F. Stephan *et al.*
FLASHlab@PITZ: Eine vielseitig verwendbare Plattform für Bestrahlungen mit Elektronen bei konventionellen und ultrahohen Dosisraten.
56. Jahrestagung der Deutschen Gesellschaft für Medizinische Physik, Berlin (Germany), 24 Sep 2025 - 27 Sep 2025. PUBDB-2025-04110.

E. Tarakci.
Future of Radiotherapy: Introducing FLASHlab @PITZ.
HZI Biomedical Engineering Workshop, Zeuthen (Germany), 21 Jan 2025 - 21 Jan 2025. PUBDB-2026-00235.

E. Tarakci.
Normal tissue sparing with electron beams at PITZ: first irradiation study in zebrafish embryos.
FRPT 2025, Prague (Czech Republic), 10 Dec 2025 - 12 Dec 2025. PUBDB-2026-00240.

J. C. Wood *et al.*
Progress in Experimental Plasma Wakefield Acceleration at FLASHForward, DESY.
International Workshop on Future Linear Colliders 2025, Valencia (Spain), 20 Oct 2025 - 24 Oct 2025. PUBDB-2025-05721.

D. Xu *et al.*
Preliminary Simulation of Terahertz Superradiance Generation at PITZ.
15th Terahertz Young Scientists Meeting, Espoo (Finland), 13 Aug 2025 - 15 Aug 2025. PUBDB-2026-00328.

S. Zeeshan.
Beam dynamics Optimization for a High-brightness PhotoInjector with various Photocathode Laser Pulse Shapes.
13th MTARD ST3 Meeting 2025 at DESY in Zeuthen, Zeuthen (Germany), 25 Jun 2025 - 27 Jun 2025. PUBDB-2026-00329.

Thesis

Ph.D. Thesis

C. Braun.
Stretcher and Amplifier design for the LPA Drive Lasers ANGUS and KALDERA.
Universität Hamburg, 2025.

L. Huebner.
Beam Transport for a Laser-Plasma Driven Free-Electron Laser at the LUX Experiment.
Universität Hamburg, 2025.

J. Kaiser.
Reinforcement Learning and Differentiable Simulations for Autonomous Tuning and Control of Linear Particle Accelerators.
Technische Universität Hamburg, 2025.

E. S. H. Musa.
Optics measurement and correctionfor future electron circular colliders.
Universität Hamburg, 2025.

Master Thesis

N. Khachatrian.
Passive stabilisation of the injection dynamics in a laser-plasma accelerator using an elongated focus.
University of Hamburg, Hamburg, 2025.

L. Niggemeier.
Development of a High-Sensitivity Wavefront Sensor for Studying Electron Stability in High-Average-Power Laser-Plasma Accelerators.
University of Hamburg, Hamburg, 2025.

L. J. Thrun.
Design of a pre-pulse generation setup to form self-aligned waveguides for stable guiding in a laser plasma accelerator.
University of Hamburg, Hamburg, 2025.

Bachelor Thesis

J. Ademoye.
Magnetometric Studies on Flux Trapping Sensitivity of Super-conducting Radiofrequency Cavities.
University of Hamburg, Hamburg, 2025.

H. Dostal.
Machine-Learning-Driven Fault Detection of a High-Power Laser.
University of Hamburg, 2025.

N. T. Eckert.
Investigations and Considerations of Oxygen Diffusion Profiles in Superconducting Mid-T RF Cavities Utilizing EXAFS Spec-troscopy.
University of Hamburg, 2025.

M. Hämmerling.
Design of Optimised Attenuators for High-Energy X-rays Using Bayesian Optimisation.

University of Hamburg, 2025.L. R. Kahl.
Effect of the cooldown velocity on the performance of supercon-ducting cavities.
University of Hamburg, 2025.

C. A. Schulze.
Effects of X-ray Radiation on Zebrafish Embryos.
Technische Hochschule Wildau, Wildau, 2025.

A. Sinn.
Effect of Dynamic Ion Motion in Plasma Accelerators Using Advanced Numerical Methods.
University of Hamburg, 2025.

Supercon-ducting technologies

With its unique test facility capacities, DESY develops recipes for supercon-ducting radio frequency (SRF) cavities to enhance cryogenic performance, paving the way for next-generation SRF technology. A nine-cell SRF cavity (left) - shown here together with an SRF gun and a single-cell cavity - is being prepared for testing in a cryostat at -271°C , the operating temperature of the European XFEL.

Picture: Thorsten Büttner, DESY



DESY campus in motion

Artistic view of the planned DESY campus with the flagship project PETRA IV: The DESY campus is in a phase of dynamic change as the research centre prepares for the future. With PETRA IV at its core and new facilities such as the DESYUM visitor centre, the Centre for Accelerator Science and Technology (CAST) and the DESY Innovation Factory as an integrated technology and start-up centre, the campus is rapidly evolving into a next-generation hub for cutting-edge research, innovation and discovery.

Picture: Science Communication Lab for DESY



Photographs and graphics

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Helmholtz contributes to solving major challenges facing society, science and the economy through top-level scientific achievements in six research fields: Energy, Earth and Environment, Health, Information, Matter as well as Aeronautics, Space and Transport. With about 46 000 employees at 18 research centres and an annual budget of more than 6 billion euros, Helmholtz is Germany's largest scientific organisation. Its work is rooted in the tradition of the great natural scientist Hermann von Helmholtz (1821–1894).

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