European XFEL

ANNUAL REPORT

European X-Ray Free-Electron Laser Facility GmbH

2011

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

European XFEL

2011

ANNUAL REPORT

European X-Ray
Free-Electron Laser
Facility GmbH

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Left to right Massimo Altarelli, Andreas S. Schwarz, Claudia Burger, Thomas Tschentscher, and Serguei Molodtsov

Dear Readers,

This annual report reflects the remarkable progress of the European XFEL project in 2011, the second full year of activity of the European XFEL GmbH. The most visible part of this progress is civil construction. Tunnelling work has continued vigorously, reaching a high point in the summer, when the last part of the 2 km long accelerator tunnel was excavated. We have also made good progress on the impressive seven-storey deep underground injector building and have started construction of the above-ground buildings, which are now visible on the DESY-Bahrenfeld site.

Most of the technical components for the accelerator were ordered in 2011. For other components of the facility, such as the undulator segments, a successful completion of the prototyping phase is now opening the way to mass production. Four of the six scientific instruments that are planned to be ready for “day one” operation passed their conceptual design reviews, as did the X-ray beam transport and optics layout. The present design of the X-ray beam transport system will enable us to manipulate, transport, and deliver photons in a range of wavelengths that greatly extends what was originally planned in the technical design report of 2006. This extension was made possible by recent advances in the rapidly evolving technology of free-electron lasers (FELs). The X-Ray Photon Diagnostics, Detector Development, and DAQ and Control Systems groups progressed in their activities, and new groups were formed to take up the development of optical lasers and sample environment systems. The Simulation of Photon Fields group also played an important role in supporting the optical design of some work packages. In addition, the group leader, together with two scientists from Deutsches Elektronen-Synchrotron (DESY), proposed a self-seeding scheme for FELs that promises a vast improvement of the spectral properties of X-ray pulses. This scheme is receiving considerable attention all over the world.

Our administration went through unusual times. The search for a successor to Administrative Director Karl Witte took longer than expected, but eventually reached a very positive conclusion, as the new Administrative Director, Dr Claudia Burger, was appointed and ready to take over on 1 January 2012.

There was intense recruiting activity in 2011. In the course of the year, our staff grew from 75 employees to almost 120. Our efforts to build up a workforce that is well-balanced in terms of age and nationality have been successful and will continue in the future, as will our efforts to achieve an even better gender balance. At European XFEL, we are dedicated to fostering an international and team-oriented corporate culture. We regard highly motivated employees as essential to our success.

One year ago, it became apparent that the high price of the underground construction, the decision of some countries to reduce or cancel their participation, and our strong determination to keep the project at the forefront of science—in friendly competition with facilities in Japan and the USA—led to a difficult financial situation. Fortunately, our major shareholders, Germany and Russia, took a strong initiative to fill the funding gap and subsequently received the support of other partner countries. We are grateful for this strong support, which allows us to look to the future with confidence, despite the continuing challenge of keeping the project within budget and on schedule. In this spirit and in close collaboration with DESY, steps were taken at the end of 2011 to improve project scheduling and monitoring even further by restructuring and strengthening the Technical Coordination group as we prepare for the imminent start of infrastructure installation in the tunnels.

We wish to thank all those who contributed to the progress of the project within our company, on its supervisory and advisory committees, at the institutes collaborating with us, and in the science community at large. We hope that readers will find this annual report informative, interesting, and pleasant to read.

Massimo Altarelli

Claudia Burger

Managing Directors

Serguei Molodtsov

Andreas S. Schwarz

Thomas Tschentscher

Scientific Directors

Robert K. Feidenhans'l

Dear Readers,

It is a great honour and pleasure for me to be the council chairman of a facility that will set new standards in X-ray science. In recent years, tremendous progress has been made in this field, due in large part to the incredible advances in the development of X-ray free-electron lasers. A significant part of this development is being pushed forward by the staff and future users of the European XFEL. The construction of below- and above-ground buildings on all three sites of the facility—DESY-Bahrenfeld, Osdorfer Born, and Schenefeld—is in full swing, and the design and construction of the accelerator and beamlines are fully on track.

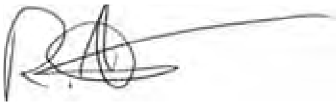
The European XFEL Council met three times in 2011, taking note of the reports by the European XFEL Council Chairman, Management Board, Administrative and Finance Committee (AFC), Machine Advisory Committee (MAC), and Scientific Advisory Committee (SAC). The council discussed and decided on a number of important issues concerning staff, legal matters, in-kind contributions, and project management as well as financial and organizational matters. Among other important decisions, the council resolved in 2011 to keep the originally planned 17.5 GeV maximum electron energy for the accelerator. This decision ensures that the facility will be highly competitive, with the greatest possible flexibility to respond successfully to future developments.

The staff of European XFEL is expanding rapidly. Every time I come to the current offices in Albert-Einstein-Ring, I see many new faces. I am especially pleased to report that nearly all of the positions for leading scientists—who will play a major role in developing the scientific opportunities of the facility—are filled.

I would like to thank the staff and management board of European XFEL for their continued hard work and dedication to the project. I would also like to extend special thanks to former Administrative Director Karl Witte, who retired at the end of 2011, for his invaluable contributions to securing the legal and administrative basis for the European XFEL GmbH.

At the same time, I would like to welcome the new European XFEL Managing and Administrative Director, Dr Claudia Burger, who started on 1 January 2012. I am sure that, together with her colleagues from the management board and the entire staff of the company, she will overcome all of the known and unknown challenges ahead of us as we complete the task of building a fully operational user facility.

I look forward to further success in 2012.

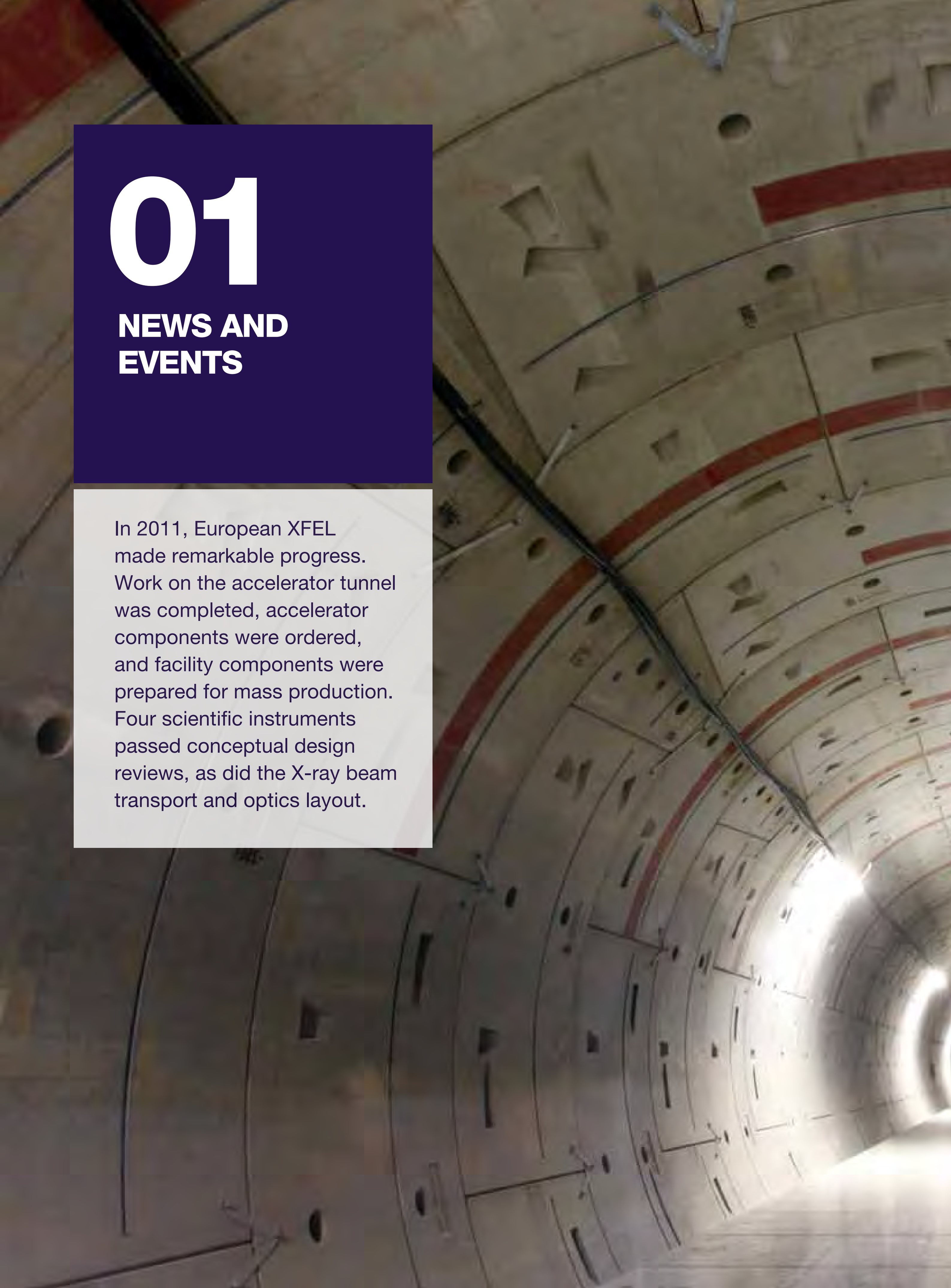


Robert K. Feidenhans'l

Chairman of the European XFEL Council

01 NEWS AND EVENTS

In 2011, European XFEL made remarkable progress. Work on the accelerator tunnel was completed, accelerator components were ordered, and facility components were prepared for mass production. Four scientific instruments passed conceptual design reviews, as did the X-ray beam transport and optics layout.



January 2011

11 January
Second tunnel boring machine AMELI powers up

The second tunnel boring machine for the European XFEL powers up, drills through the wall of the future experiment hall, and begins digging into the soil beyond. Until summer 2012, AMELI (German acronym for “At the end there will be light”) will excavate the “tunnel fan” in which the X-rays will be generated.

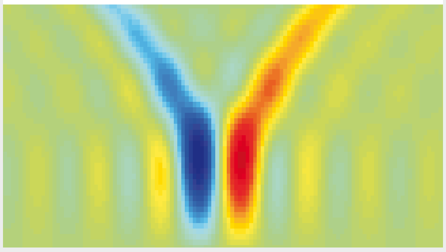
The fan will comprise eight tunnel sections with an internal diameter of 4.6 m and a total length of 2 693 m. Constructing so many short tunnel sections is a challenge because the colossal machine must be disassembled four times, transported back to its new launch point inside the future experiment hall, and then reassembled.

February 2011

2 February
Terahertz flashes enable accurate X-ray measurements

A research group from European XFEL, Deutsches Elektronen-Synchrotron (DESY), Helmholtz-Institut Jena, and Helmholtz-Zentrum Berlin (HZB) succeeds in measuring the arrival time of X-ray pulses generated by a free-electron laser with a precision of less than 10 fs.

The new method was developed at the Free-Electron Laser in Hamburg (FLASH) for pump-probe processes, where a first ultrashort pump pulse triggers a photochemical reaction and a second pulse takes a “photograph”. Using an intense terahertz flash emitted with a controlled time separation from the X-ray pulse, researchers can now determine exactly at what time the picture produced by the second pulse is created. Processes can now be studied with X-rays on the femtosecond time scale—something scientists have long awaited.



March 2011

23 March
Two premieres for the accelerator construction

The first accelerator module assembled at Commissariat à l’Énergie Atomique et aux Énergies Alternatives (CEA) in Saclay, France, and the first of three cryogenic test benches manufactured at Budker Institute of Nuclear Physics (BINP) in Novosibirsk, Russia, arrive at DESY.

The prototype module for the superconducting linear accelerator, which had been disassembled and reassembled for test purposes at CEA in Saclay, is brought into the hall by truck, unloaded, and mounted on the test bench. This test bench—a roller bearing support with the required cryogenic components—was manufactured at BINP. It is the first in-kind contribution to the European XFEL delivered by a partner country.

April 2011

May 2011

24 March
First call for expressions of interest from user consortia

European XFEL issues a call for expressions of interest in the construction and financing of the scientific instruments at the facility, following a decision by the European XFEL Council to welcome such contributions by user consortia. Nine expressions of interest were received by the deadline for this first call in June 2011.

28 March
AMELI reaches first milestone

After almost 12 weeks, the tunnel boring machine AMELI breaks through the wall of its first reception shaft, completing the 544 m long tunnel section XTD9. Christiane Küchenhof, Schenefeld Mayor and patroness of the tunnel boring machine, greets the AMELI team.

1 April
China's IHEP delivers undulator prototype

In the context of a long-time German–Chinese collaboration, the Institute of High Energy Physics (IHEP) in Beijing completes the first undulator segment for the European XFEL and delivers it to the undulator test rooms.

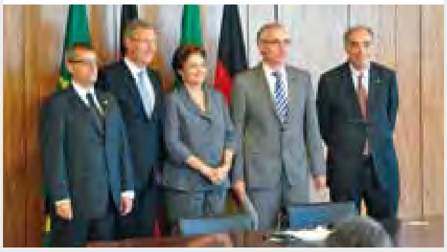
Two rows of 207 magnets each make up the 5 m long, 2.28 m high undulator segment, manufactured with micrometre precision. IHEP built the prototype at its own expense on the basis of existing plans.

The prototype is the first undulator segment constructed specifically for the European XFEL. It is the result of a long-term collaboration between Beijing and Hamburg. After extensive testing, it will be one of the 91 segments that make up the undulator sections for the first three beamlines of the European XFEL.

5 May
Cooperation agreement signed in Brasília

In the presence of German President Christian Wulff and Brazilian President Dilma Rousseff, the directors of DESY, European XFEL, and the Brazilian synchrotron radiation laboratory (LNLS) sign a cooperation agreement in Brasília.

One of the ideas of this trilateral cooperation agreement is to attract Brazilian students and post-doctoral researchers to DESY and European XFEL. For both organizations, the cooperation agreement with LNLS is the first partnership with a Latin American research institute. It was developed during the German–Brazilian science year 2010–2011.



June 2011

22 June
Topping-out ceremony for the injector building

The first topping-out ceremony for one of the underground buildings of the European XFEL facility is celebrated on the DESY-Bahrenfeld construction site: the shell of the underground injector complex, which is 100 m long and seven storeys deep, has reached the surface.

The construction work for the huge building started in May 2010. The completed building—which consists of two shafts and two 20 m connecting tunnels on top of each other—is to be handed over in spring 2012.

30 June
X-ray flashes revised

Recent developments demonstrate that the parameters of the X-ray flashes that will be generated by the European XFEL can be improved beyond the original design. This improvement will tune the light even more to user needs.

Experience with the Linac Coherent Light Source (LCLS) X-ray free-electron laser at SLAC National Accelerator Laboratory in California, as well as results at the Photo Injector Test Facility (PITZ) at DESY in Zeuthen, show that a much better electron beam quality can be achieved at the European XFEL than previously assumed. This results in an updated undulator layout for the European XFEL, which is published in a technical report.

The improved electron beam quality will enable the generation of X-ray pulses with wavelengths down to 0.05 nm, instead of the 0.1 nm originally foreseen in the 2006 technical design report, and pulse durations down to 2 fs, instead of 100 fs.

30 June
Farewell with overtime

European XFEL says farewell to Administrative Director Karl Witte—at least formally. Witte, aged 67, remains on duty until the search for his successor is concluded at the end of the year.

One of the architects of European XFEL, Witte has been in charge of the legal texts for the project, including founding documents such as the international convention governing the construction and operation of the facility. Ever since European XFEL was founded, Witte has been responsible for administrative matters as one of its two managing directors.

July 2011

27 July
Boring of accelerator tunnel completed

The tunnel boring machine TULA ("tunnel for laser") reaches its final destination. With a landing precision of 1 mm, TULA arrives in its travel-out panel on the western wall of the injector building on the DESY-Bahrenfeld site. A few days later, the tunnel builders install the last concrete ring of the 2 010 m long tunnel for the accelerator.

August 2011

15 August
Cooperation agreement with University of Hamburg

With their signature, representatives of European XFEL and the University of Hamburg formalize the research and teaching cooperation with the university's School of Mathematics, Informatics, and Natural Sciences (MIN).

The main focus will be on exchanging know-how, implementing joint research projects, providing mutual access to experiment facilities, and promoting undergraduates, Ph.D. students, and young scientists. In practice, the partners have already cooperated successfully for several months on various projects. With the formal agreement, the momentum of this cooperation can now increase.

September 2011

12 September
EMBL and European XFEL bundle expertise

By signing a memorandum of understanding, the European Molecular Biology Laboratory (EMBL) and European XFEL lay the foundation for a close future collaboration. EMBL is Europe's top address for biological research on the molecular level. The European XFEL will be ideally suited for deciphering the structure and dynamics of biomolecules. Both organizations will thus benefit from bundling their expertise.

21 September
Topping-out ceremony for modulator hall

Just three months after the start of construction, the completion of the modulator hall is celebrated at a topping-out ceremony. With floor space of over 2 500 m^2 and a height of almost 11 m, the building is one of the largest on the DESY-Bahrenfeld site. The hall will house the modulators, which process the power needed for the acceleration of the electrons.

October 2011

6 October

Spain officially joins European XFEL

Spain becomes an official European XFEL partner. Representatives of Spain and the other 11 contract parties sign the protocol of accession in Berlin in the presence of the two European XFEL Managing Directors. Spain is thus the twelfth country to participate in the construction of the European XFEL facility.

10 October

European XFEL cooperates with Spanish laser facility

European XFEL and the Spanish Center for Ultrashort Ultraintense Pulsed Lasers (CLPU) in Salamanca sign a memorandum of understanding expressing their intention to cooperate. The two research institutions will join their efforts to promote research in high energy density science and develop new ultrafast lasers.

These optical lasers will be used to analyse physical and chemical processes in conjunction with the X-ray beams of the European XFEL. Optical lasers are needed to heat materials or excite molecules to produce high energy density materials like plasmas, or to start chemical reactions, which will then be analysed using the X-ray flashes of the European XFEL.

In 2011, an optical laser expert from CLPU joins the European XFEL Optical Lasers group for an initial period of six months.

17 October

European XFEL participates in EU research network CRISP

Representatives from 16 research institutions, among them European XFEL, meet at the Czech embassy in Paris to kick off the Cluster of Research Infrastructures for Synergies in Physics (CRISP), a new EU research network that comprises 11 European research infrastructures currently being planned or under construction.

The cooperation focuses on four key areas of physics, all of which are important for the European XFEL: accelerator technology, physics instrumentation and experiments, detectors and data acquisition technologies, and IT and data management systems. CRISP is funded by the European Commission within the 7th Framework Programme.

CRISP

The CRISP partners will exchange know-how and experience to develop new key technologies in Europe in a cost-effective and coordinated way.

December 2011

21 October

First deliveries from Poland to European XFEL

The first segments of a helium transfer line required for testing the European XFEL accelerator elements arrive from Poland.

Poland participates in the construction of the European XFEL facility by providing an in-kind contribution that includes the delivery of special cryogenic components. In addition, experts from Polish institutes are responsible for the comprehensive quality tests of the superconducting niobium resonators and accelerator modules, which will be carried out at the DESY Accelerator Module Test Facility (AMTF).

The cryogenic plant that will produce the liquid helium at a temperature of -271°C already exists at DESY, about 150 m away from the AMTF hall. The complex transfer line will allow the ultracold helium to be transported from the cryogenic hall to the AMTF hall without heating up.

29 October

Visitors find out more about European XFEL

From noon to midnight, DESY opens its doors to the public. One of the venues that attract great interest is the European XFEL exhibition “Licht der Zukunft” (“Enlightening Science”) in the large undulator test hall, which is attended by many of the more than 13 000 visitors.

The exhibition centres on the undulator segments in which the X-ray flashes of the European XFEL will be generated. It also includes prototype components of the future detectors, a model of the tunnel boring machine, movies, and numerous posters, as well as physics experiments.

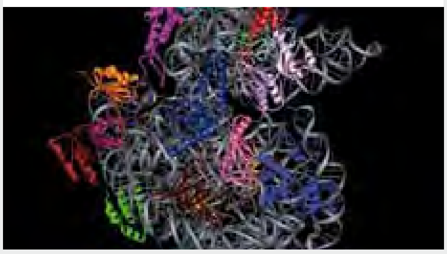
16 December

European XFEL joins BioStruct-X consortium

European XFEL joins a number of research institutions, led by the European Molecular Biology Laboratory (EMBL), in the new EU-funded consortium BioStruct-X.

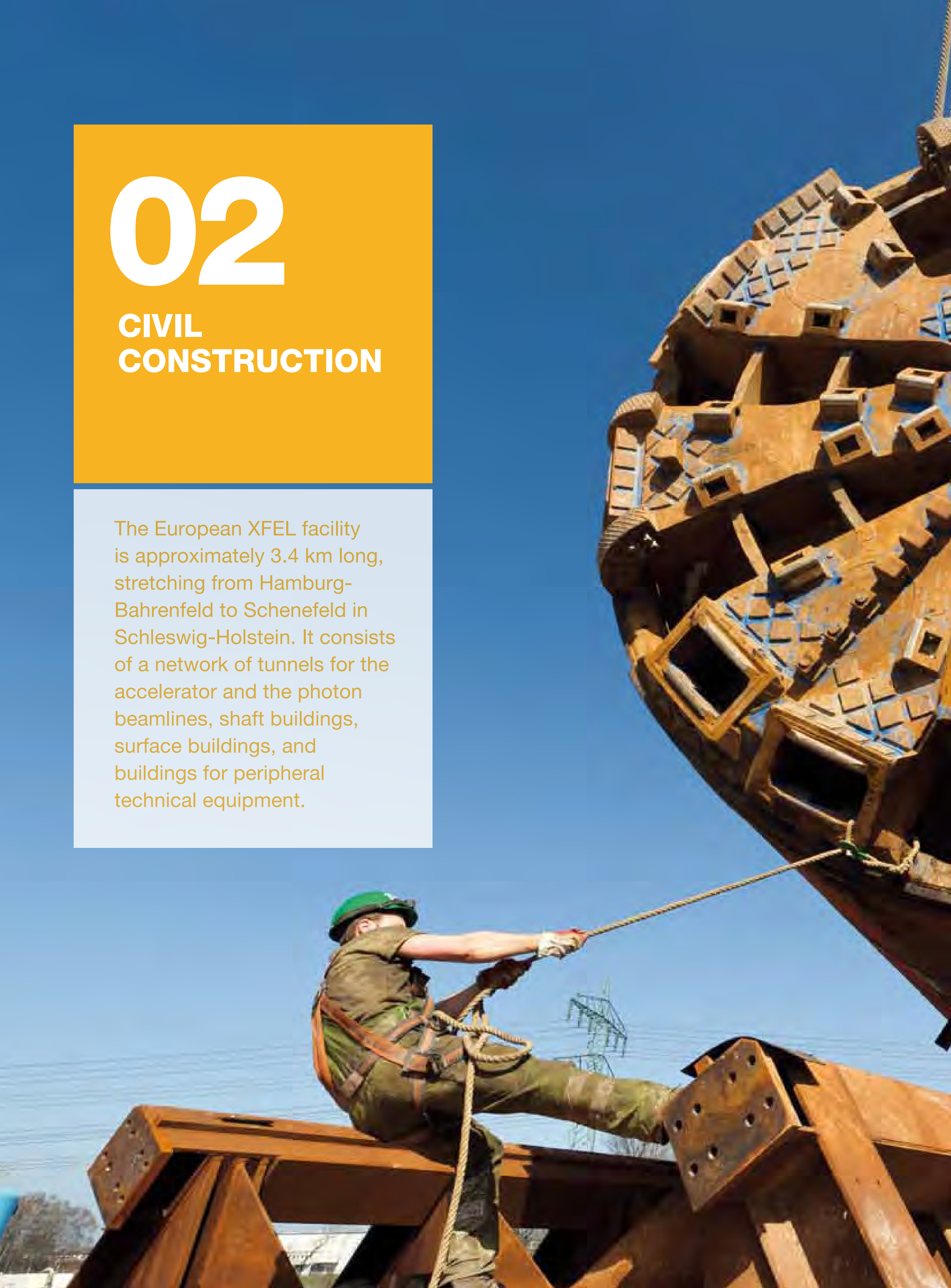
BioStructX

One goal of the new consortium is to make crystallographic data from X-ray free-electron lasers (FELs) interpretable in a way similar to synchrotron-based data. The pulses from X-ray FELs are up to a billion times brighter than X-ray beams from synchrotrons, allowing diffraction patterns to be collected from very small biological samples. Without the need to prepare large crystals, years of effort could be saved.



02
CIVIL CONSTRUCTION

The European XFEL facility is approximately 3.4 km long, stretching from Hamburg-Bahrenfeld to Schenefeld in Schleswig-Holstein. It consists of a network of tunnels for the accelerator and the photon beamlines, shaft buildings, surface buildings, and buildings for peripheral technical equipment.



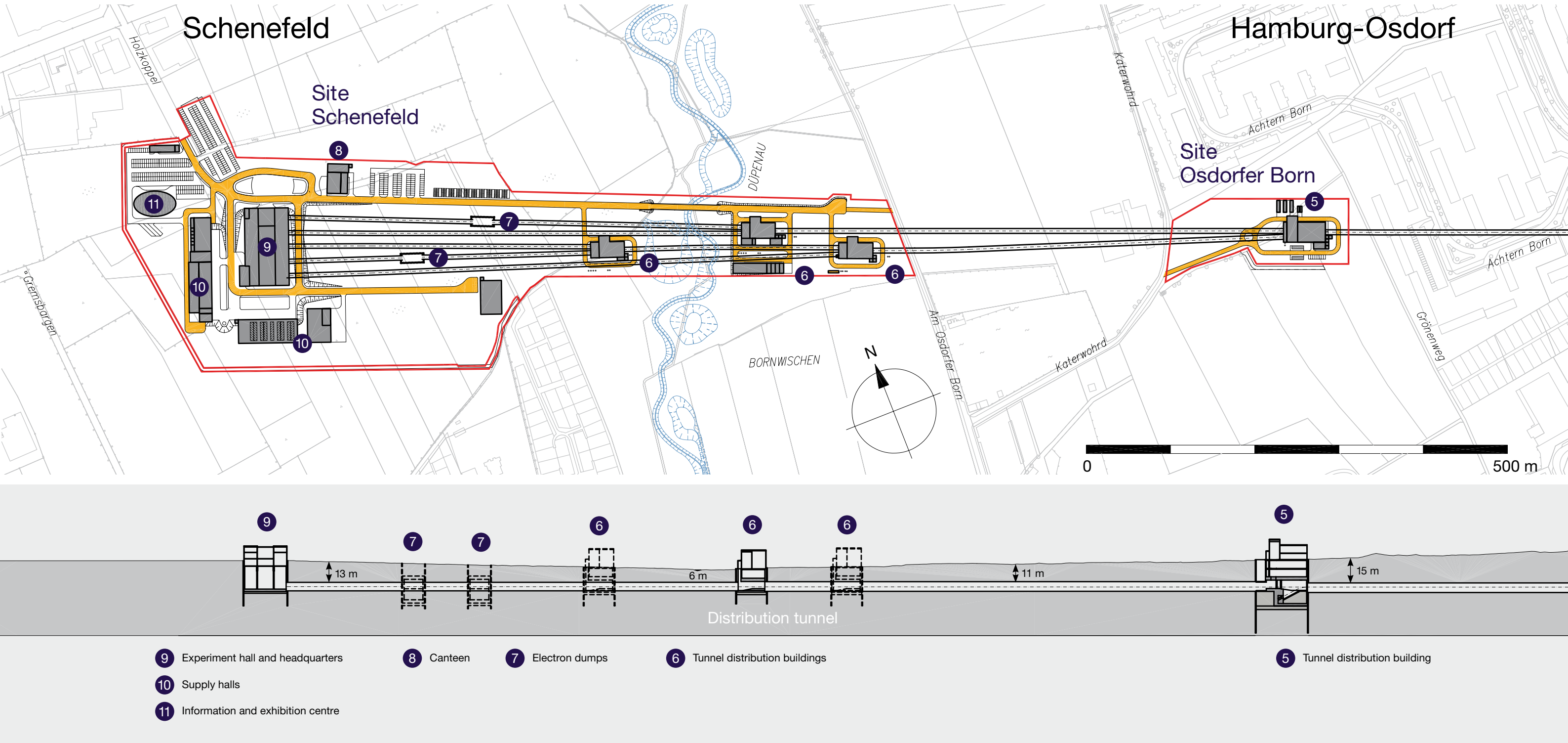


Figure 1 Layout of the European XFEL facility

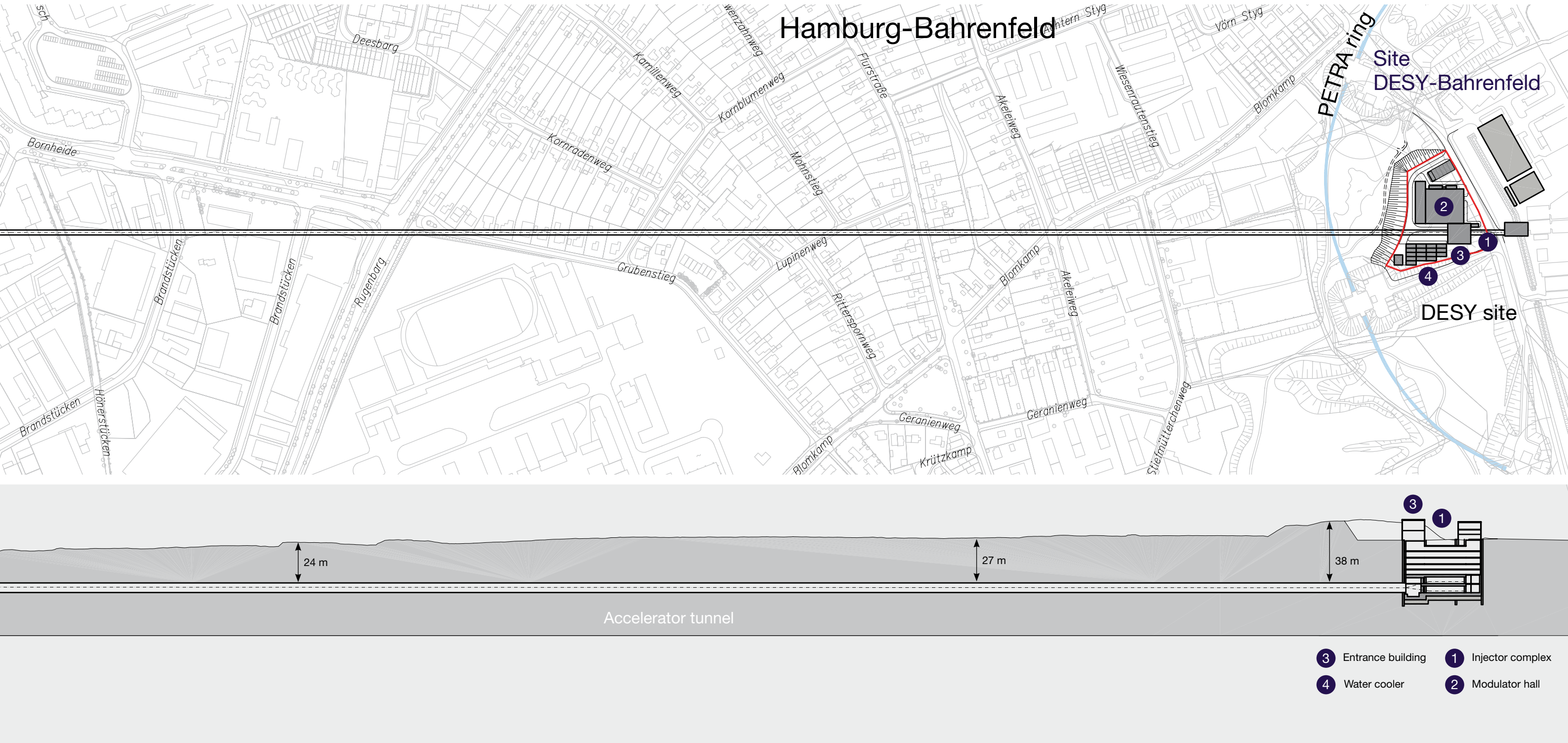
CIVIL CONSTRUCTION

In 2011, the civil construction project proceeded according to plan and all major milestones were met. Work concentrated on the drilling of various tunnels as well as the construction of the seven-storey-deep underground injector building and the modulator hall, the first surface building on the DESY-Bahrenfeld site.

Overview

The overall layout of the European XFEL facility is shown in Figure 1. The top view indicates the dimensions and the placement in the surrounding area. The side cross-sectional view shows the ground profile and the various shaft buildings.

The facility is approximately 3.4 km long and stretches from Deutsches Elektronen-Synchrotron (DESY) in Hamburg-Bahrenfeld all the way to the southern edge of the city of Schenefeld in the German federal state of Schleswig-Holstein. It consists of a large network of tunnels for the accelerator and the photon beamlines plus eight shaft building complexes, corresponding surface buildings, and assorted building structures for peripheral technical equipment (for example, pump housing, generators, and air conditioning). Most of the facility lies underground. The network of tunnels has a total length of about 5.77 km.

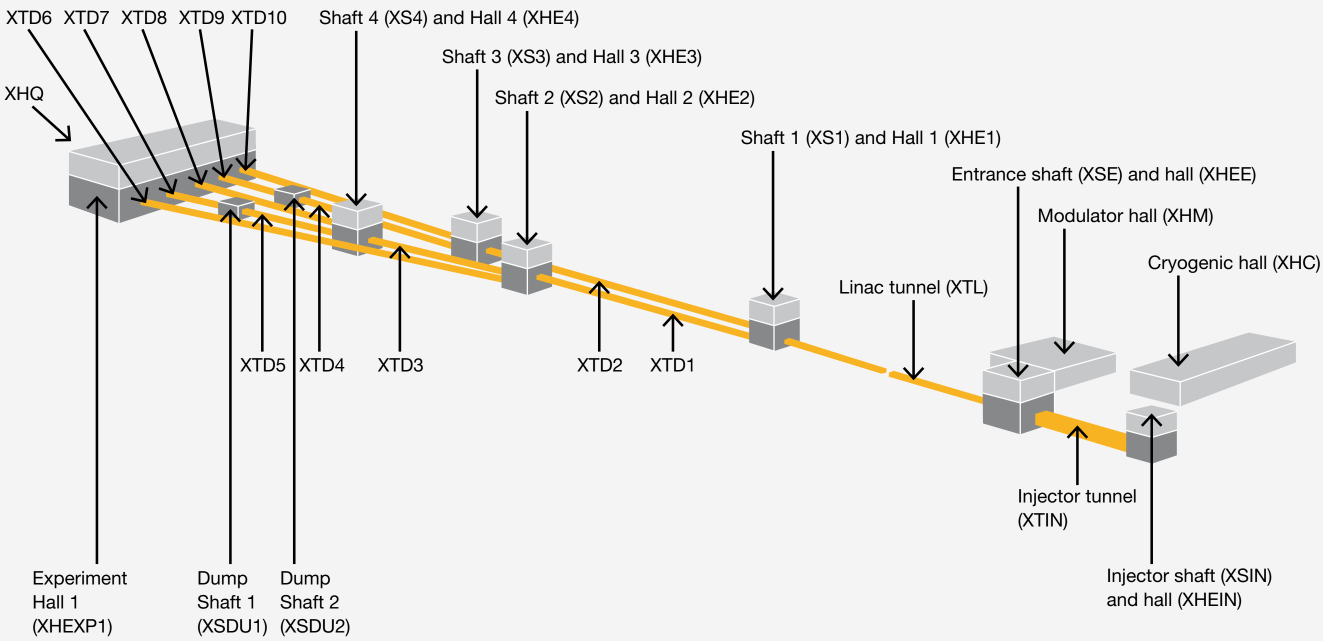


The heart of the facility will be the underground experiment hall in Schenefeld, with a large laboratory and office building on top. The latter will serve as the European XFEL headquarters. Figure 2 on the following page shows a schematic view of all the underground and surface buildings of the European XFEL facility.

Status of tunnel construction—December 2011

The tunnel digging is performed with two tunnel boring machines (TBMs), one called "TULA" ("tunnel for laser") and the other called "AMELI" ("*Am Ende Licht*", meaning "light at the end of the tunnel"). The TBMs have different diameters to accommodate the different tunnel sizes for the accelerator and photon tunnels, respectively. Excavation of a tunnel section always begins at a given start shaft, from which the TBM advances about 10–13 m per day. At its target shaft, it is dismantled and moved to the next start shaft. Given the size of the machines, this is a time-consuming process. For example, TULA is 71 m long, weighs 550 t, and has a cutting wheel 6.17 m in diameter.

In January 2011, TULA was ready to start the 2.1 km long tunnel for the linear accelerator. Seven months later, it reached its destination, the entrance shaft on the DESY-Bahrenfeld site, where it was then dismantled and removed.



Type	Building		
X = XFEL	C = Cryo (cooling)	EE = Entrance hall of entrance shaft	L = Linear accelerator
H = Hall	D = Distribution (switchyard tunnel)	EXP = Experiment	M = Modulator
S = Shaft	DU = Dump (beam absorber)	HQ = Headquarters	
T = Tunnel	E = Entrance	IN = Injector	

Figure 2 Buildings of the European XFEL facility

Figure 3 TULA being moved into its starting position in Shaft 1 (January 2011)

Towards the end of 2010, TULA finished drilling the first two undulator tunnels (XTD1 and XTD2). On 20 January 2011, it was ready to start the 2.1 km long tunnel for the linear accelerator (XTL). Figure 3 shows TULA being moved into its starting position in Shaft 1 (XS1) in early January.

In late July, after a long journey, TULA reached its destination, the entrance shaft (XSE) on the DESY-Bahrenfeld site, where it was then dismantled and removed. Figure 4 shows the removal of the cutting wheel in the narrow XSE.

The second TBM, AMELI, with a slightly smaller cutting wheel, was set up in the future experiment hall (XHEXP1) to start on the first tunnel for the photon beamlines (XTD9). Figure 5 shows the machine in its starting position in late November 2010.

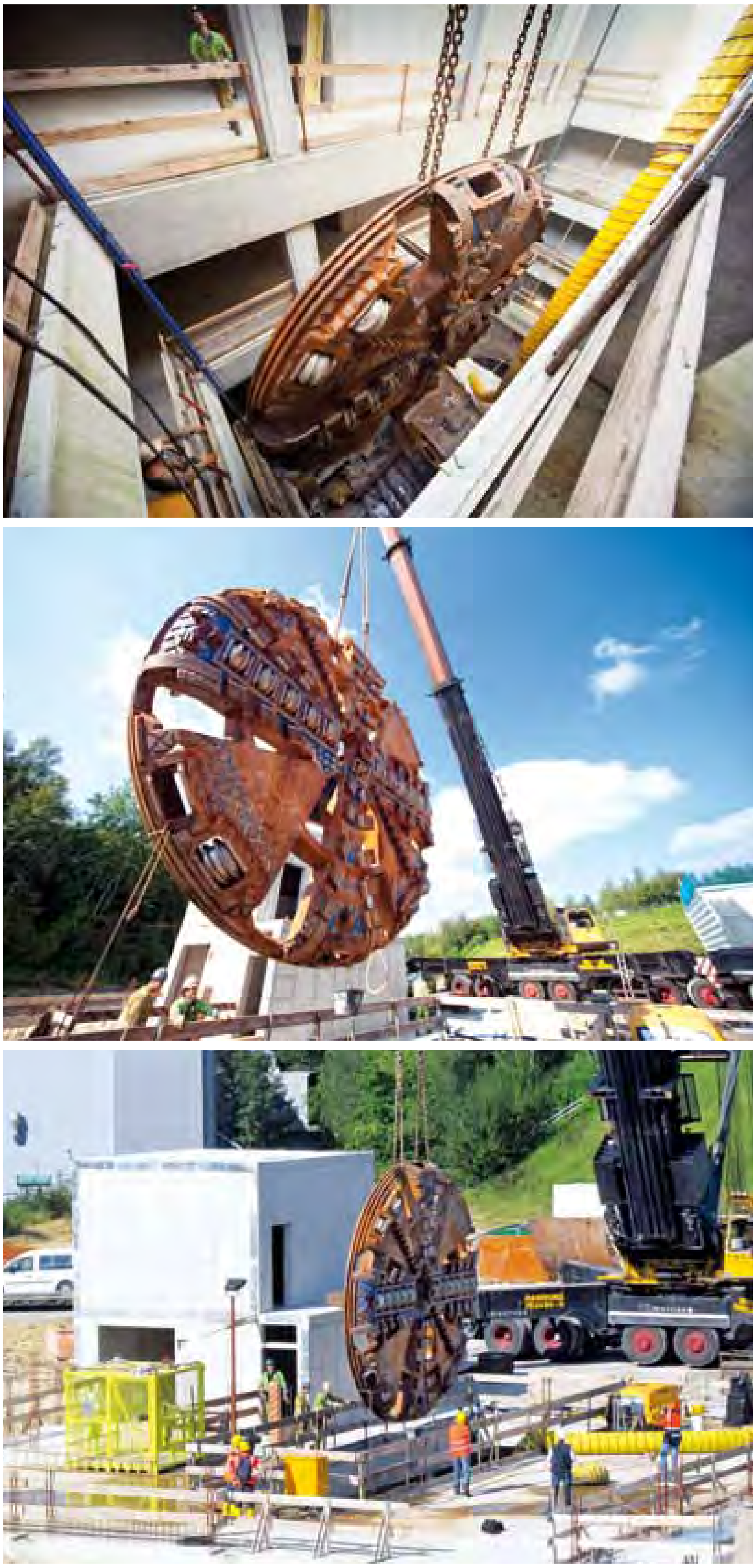


Figure 4 Removing the cutting wheel of TULA in the entrance shaft

Figure 5 AMELI in its starting position (November 2010)

Figure 6 AMELI travelling from a target shaft back to the experiment hall

The machine made rapid progress. At the end of 2011, only the tunnel sections XTD3, XTD6, and part of XTD5 remained to be drilled, and more than 80% of the entire 5.77 km long tunnel network had been excavated. Figure 6 shows the head structure of AMELI on one of its many travels from a target shaft back to its start shaft at the experiment hall (XHEXP1).

After the completion of each tunnel shell, work started on the construction of the tunnel floor. Figure 7 shows the installation of a section of the complex floor construction in the linear accelerator tunnel (XTL). Cables and other infrastructure will later be placed below the floor slabs.

Figure 8 shows a corresponding view into the first undulator tunnel (XTD1). Here the floor is simply built from steel-reinforced concrete.

DESY-Bahrenfeld site

Figure 9 shows an aerial view of the injector complex region on the DESY campus in September 2011. The very deep shaft complex for the injector building had already been refilled. Work is still going on to finish the various walls for the many rooms of the seven-storey underground building as well as the elevator shafts, which are the only structures of the injector building that can be seen above ground. Also seen in the figure are the first hall buildings for the European XFEL: the hall of the Accelerator Module Test Facility (AMTF), completed in 2010, and the modulator hall. The topping out of the modulator hall was celebrated in September 2011.

Figure 7 Floor construction in the linear accelerator tunnel

Figure 8 Floor construction of the first undulator tunnel

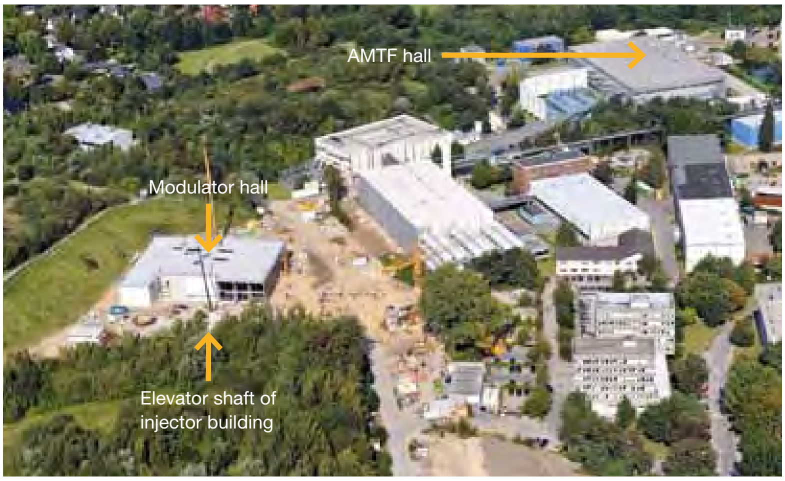


Figure 9 Aerial view of the injector complex region (September 2011)

Osdorfer Born site

At Shaft 1 (XS1) in Osdorfer Born, the linear accelerator tunnel (XTL) ends and the first two undulator tunnels (XTD1 and XTD2) begin. Figure 10 shows an aerial view of the site in September 2011. Shaft 1 was essentially used as target and start shaft, respectively, for TULA, the TBM that bored the tunnels XTD1, XTD2, and XTL. Work on the interior of the shaft will start after the tunnel floors have been completed.

At Shaft 1 in Osdorfer Born, the linear accelerator tunnel ends and the first two undulator tunnels begin. Work on the interior of the shaft will start after the tunnel floors have been completed.

Schenefeld campus

On the Schenefeld campus, work concentrated on the tunnelling (Figure 11). Since the shafts are all needed as start or target shafts for the construction of a given tunnel section, work on their interior was very limited, with the exception of the future experiment hall, where work on the floor and the first walls of the building inside the concrete hull started.

In parallel, the site of the future experiment hall is still being used to provide the infrastructure and material required by AMELI for boring the remaining tunnel sections, XTD3 and XTD6.

Figure 10 Aerial view of the Osdorfer Born site (September 2011)

Figure 11 Aerial view of the Schenefeld site (September 2011)

Figure 12 shows an overview of the 4 500 m^2 experiment hall (XHEXP1). The construction walls on the right support and guide AMELI into the individual tunnel segments XTD6 to XTD10. In the front, work for the construction of the thick floor plate made of steel-reinforced concrete is continuing. In the back, the construction of the first wall of the hall building is in progress.

Architecture

To create a uniform and unique appearance for the various technical surface buildings of the European XFEL and to illustrate that the various buildings, spread over a distance of several kilometres, belong to the same large underground facility, an architect's office was engaged for the planning of the facades of the industry-type access shaft buildings.

Since the overall size, layout, and placement of the buildings was already determined in the course of the plan approval process in 2005–2006, and since the amount of resources to be spent on the architecture was to be kept to a minimum, the architects focused on issues such as the colour and texture of the buildings' surfaces.

Figure 13 shows the design of the two access halls—the entrance hall (XHEE) and the injector hall (XHEIN)—located at the DESY-Bahrenfeld site. The colour of the facades is anthracite, with a light grey band that can be used as a background for pictures illustrating the science related to the building. The location of the band also illustrates that the two buildings are connected to each other, forming the surface end structures of the large underground injector building complex.

Halls 1 to 4 (XHE1 to XHE4) are designed using a similar pattern. Figure 14 shows Hall 3 (XHE3) as an example.

Figure 12 Overview of the future experiment hall (November 2011)

Figure 13 Design entrance hall and injector hall

Figure 14 Design of Hall 3

Challenges

During both the tunnel construction and the installation of the floors into the tunnel XTL, several neighbours living near XTL complained about noise caused by the tunnel train that transported material and personnel to and from the TBM head, as well as noise caused by the transport vehicles used to install the heavy floor slabs. The first cause of noise disappeared with the finalization of the tunnels XTD1, XTD2, and XTL, at which point the tunnel train operation stopped. Possible noise reduction measures for the second cause are currently being investigated with the goal of minimizing the disturbance to our neighbours.

On 2 July, European XFEL was informed that a small hole had appeared in a garden above XTL. An immediate and careful analysis showed that the problem could indeed be attributed to the tunnel boring process. It was established that there was no underground cavity. The hole was filled and the earth in its vicinity compacted using special technical procedures.

In August, a resident complained about the development of small cracks in his house during the passage of the TBM. If it is established that the cause is related to the tunnel boring process, a reimbursement of the costs for repair will follow.

03

IN-KIND CONTRIBUTIONS

To a great extent, our partners contribute to the European XFEL in the form of components or human resources. To date, European XFEL has received proposals for 76 such in-kind contributions. Seventeen institutes form the Accelerator Consortium, which is in charge of constructing the superconducting accelerator.

OVERVIEW

European XFEL shareholders contribute to construction costs in cash or in kind. In-kind contributions (IKCs) can take the form of component delivery, secondment of staff, or both. To date, the company has received proposals for 76 IKCs from 10 different countries for a total of 563 million euro (M€). IKCs were first implemented in 2010. The first significant achievements were made in 2011. In addition, various IKC procedures were finalized and implemented, in particular for the validation of milestones.

Overall contributions

In 2011, four countries announced an increase in their global contribution to the European XFEL project: Germany, Poland, Russia, and Switzerland. By the end of the year, the total value of projected IKCs amounted to about 563 M€, including contracts to Russian institutes (Table 1).

Countries contributing in kind

To date, seven countries have submitted specific proposals for IKCs: France, Germany, Italy, Poland, Spain, Sweden, and Switzerland. Denmark and Slovakia have issued expressions of interest that could result in new IKCs in the near future.

Abbrevation	Country	IKC value (k€)
DK	Denmark	To be determined
FR	France	36 000
DE	Germany	411 353
GR	Greece	0
HU	Hungary	0
IT	Italy	33 000
PL	Poland	15 977
RU	Russia	44 326
SK	Slovakia	0
ES	Spain	9 199
SE	Sweden	4 192
CH	Switzerland	9 077
Total		**563 123**

Table 1 Projected IKC amounts by country (in 2005 prices) in thousands of euro (k€) as of December 2011

For Russian contributions, the IKC procedure is somewhat different than for other countries because the Russian shareholder decided to send its full contribution to European XFEL in cash rather than in kind. When a Russian institute proposes to produce a specific piece of equipment, technical and financial discussions with European XFEL result in the awarding of a manufacturing contract to the institute, which is then managed with the same procedure as an IKC.
To date, European XFEL and five Russian institutes have concluded 11 manufacturing contracts.

In all, 10 countries will deliver 76 different contributions for a total value of 563 M€ (Figures 1 and 2). This data includes the contracts with the Russian institutes.

By the end of the year, 10 countries were projected to deliver 76 different contributions for a total value of 563 million euro.

In 2011, the European XFEL Council officially allocated 13 new contributions, thus increasing the total to 28. Eleven out of 12 foreseen contracts with Russian institutes were signed. All contributions foreseen for Poland and Sweden are now formalized by signed agreements.

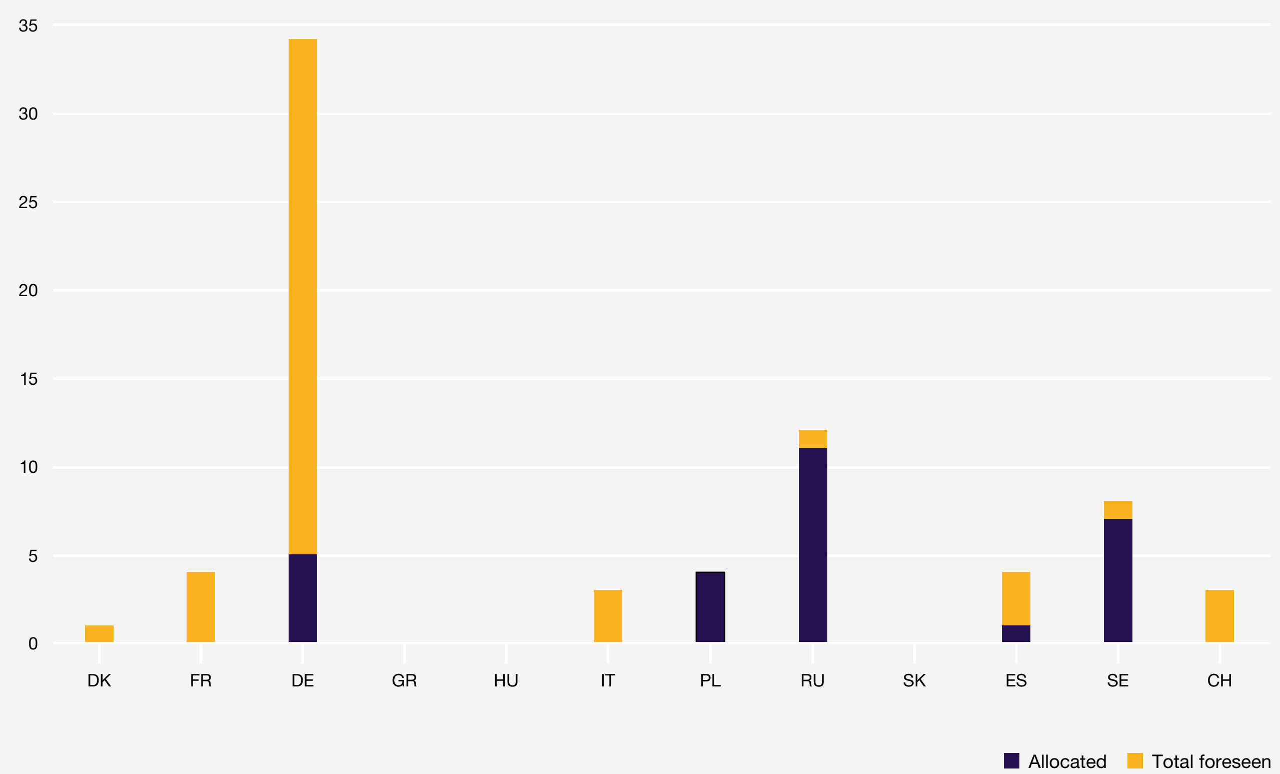


Figure 1 Number of IKCs by country

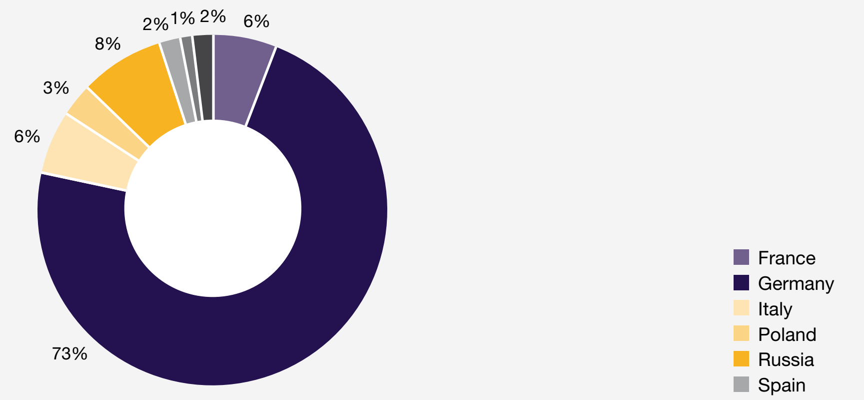


Figure 2 Distribution of IKC values

Contributing institutes

As of December 2011, 21 institutes are contributing to the European XFEL project (Table 2).

To view the latest IKCs from the different institutes, go to our new web page:

www.xfel.eu/project/in_kind_contributions

This webpage informs the scientific community and the general public about the commitments and activities of the institutes contributing to the construction and commissioning of the European XFEL facility. A progress report shows the current status of work performed at the institutes on their IKCs.

A webpage provides information about the commitments and activities of the institutes contributing to the construction and commissioning of the European XFEL facility.

IKRC recommendations

The In-Kind Review Committee (IKRC) advises European XFEL concerning proposed IKCs. The committee is composed of one representative from each contracting party and two representatives from European XFEL (one for the accelerator, one for the beamlines).

Country	Abbreviation	Institute	Location	Work Packages
DK	DTU	Technical University of Denmark – Department of Physics	Risø	81
FR	CEA	Commissariat à l'Énergie Atomique et aux Énergies Alternatives	Saclay	3, 9, 17
	CNRS	Centre National de la Recherche Scientifique	Orsay	5
DE	DESY	Deutsches Elektronen-Synchrotron	Hamburg, Zeuthen	1–21, 28, 32–36, 38–40, 45, 46
IT	INFN	Istituto Nazionale di Fisica Nucleare	Milano	3, 4, 46
PL	NCBJ	National Center for Nuclear Research	Świerk	6
	IFJ-PAN	Henryk Niewodniczański Institute of Nuclear Physics	Kraków	10, 11
	WUT	Wrocław University of Technology	Wrocław	10
RU	BINP	Budker Institute of Nuclear Physics of SB RAS	Novosibirsk	8, 10, 12, 13, 19, 34
	IHEP	Institute for High Energy Physics	Protvino	13, 17, 20
	INR	Institute for Nuclear Research RAS	Troitsk	18
	JINR	Joint Institute for Nuclear Research	Dubna	74
	NIIEFA	D.V. Efremov Scientific Research Institute of Electrophysical Apparatus	St. Petersburg	12
ES	CELLS	Consortium for the Exploitation of the Synchrotron Light Laboratory	Barcelona	71
	CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Madrid	11, 71
	UPM	Universidad Politécnica de Madrid	Madrid	34
SE	KTH	Royal Institute of Technology	Stockholm	73
	MSL	Manne Siegbahn Laboratory	Stockholm	12, 71
	SU	Stockholm University	Stockholm	28
	UU	Uppsala University	Uppsala	14, 79, 84
CH	PSI	Paul Scherrer Institut	Villigen	16, 17

Table 2 Institutes contributing to the European XFEL project

The IKRC performs the following tasks:

- Reviewing expressions of interest from institutes of participating countries to contribute in kind
- Checking the suitability of specific components to be treated as IKCs (that is, whether a component can be built separately and in a different location from the other components, and then be integrated into the rest of the facility)
- Verifying that the proposing team has the technical competence and experience to perform the corresponding task
- Verifying the adequacy of the available infrastructure
- Issuing a recommendation for or against the start of the next step (that is, the drafting of a detailed agreement between European XFEL and the contributing institute)

In January, May, and October 2011, the IKRC held formal meetings in Hamburg.

During these three meetings, the IKRC analysed 11 contribution proposals presented by DESY:

- DE10: Infrastructure components for the vertical and horizontal test stands at the Accelerator Module Test Facility (AMTF)
- DE14: Injector system and coordination of contributions by Sweden
- DE17b: Standard electron beam diagnostics system
- DE19: Warm vacuum components and coordination of contributions by Russia
- DE21: Calculation of self-amplified spontaneous emission (SASE) parameters and development of free-electron laser (FEL) concepts
- DE32: Survey and alignment of components in the tunnels
- DE33: Installation of large components in the tunnels
- DE34: Utilities systems (electrical networks, cooling water, heating, and air conditioning)
- DE36: General safety in all infrastructure
- DE38: Personnel interlock system
- DE39: Electromagnetic compatibility (rules and implementation)

The IKRC recommended all of these DESY proposals for a total value of 150 M€.

As of December 2011, a total of 60 proposals have received favourable recommendations from the IKRC.

Abbreviation	Institute	IKC No.	Work package	Title
DESY	Deutsches Elektronen-Synchrotron in Hamburg, Germany	DE10	10	Cryogenics for the AMTF
		DE13	13	Cryogenic supply for the accelerator complex
		DE19	19	Warm vacuum components and coordination
NCBJ	National Centre for Nuclear Research in Świerk, Poland	PL01	6	Higher-order mode couplers and beamline absorbers
WUT	Wrocław University of Technology in Wrocław, Poland	PL04	10	Transfer line XATL1 and two vertical cryostats for the AMTF
JINR	Joint Institute for Nuclear Research in Dubna, Russia	RU03	74	MCP-based detectors in the beamlines
IHEP	Institute for High Energy Physics in Protvino, Russia	RU07	13	Cryogenic equipment for the accelerator complex
		RU09	17	Components for the beam loss monitors
BINP	Budker Institute of Nuclear Physics of SB RAS in Novosibirsk, Russia	RU18	8	Components for the cold vacuum system
		RU19	19	Components for the warm vacuum system
		RU24	13	Cryogenic equipment for the accelerator complex
CELLS	Consortium for the Exploitation of the Synchrotron Light Laboratory (CELLS) at the ALBA Synchrotron Light Facility in Barcelona, Spain	ES01	71	Seven mechanical supports for undulators
UU	Uppsala University in Uppsala, Sweden	SE01	79	Sample injector and diagnostic system

Table 3 IKCs allocated by the European XFEL Council in 2011

Council allocations

The agreements for 13 contributions were advanced enough to present proposals to the European XFEL Council for allocation (Table 3).

The European XFEL Council allocated all 13 contributions to the respective institutes for a total value of 74.9 M€.

Milestone validation

Each IKC is the object of a contract agreed between European XFEL and the shareholder or related institute involved in the production of the IKC. The progress of the contribution is monitored through specific milestones detailed explicitly in each contract. Each milestone is connected to a credit allotment for the shareholder.

According to Article 5.3 of "Internal provisions on in-kind contributions", a document annexed to the European XFEL Convention, "the Management Board shall report to the Council on the accruals of earned value for contributions in kind in relation to the expected progress".

The construction phase will include a total of about 600 milestones. A specific procedure has been established for the milestone validation in order to implement an automated and reliable process.

Consequently, European XFEL will validate the achievements specified for each milestone. It is estimated that the construction phase will include a total of 600 milestones. A specific procedure has been established for the milestone validation in order to implement an automated and reliable process (Figure 3). The same procedure is used to manage the invoices issued by the Russian institutes for the execution of the corresponding manufacturing contract.

This procedure was first implemented in 2011. Twenty-four milestones were completed and validated. A milestone database was established to follow the progress of achievements in the different contributions.

The process of validation is triggered either by a notification and credit request issued by a shareholder, informing European XFEL that a contributing institute has achieved a specific milestone, or by an inquiry sent to a shareholder by European XFEL.

Work package leaders (WPLs) play an essential role in this process. In a first (verification) step, they verify that all of the requested documents and parts are delivered. In a second (validation) step, they make sure that the deliveries satisfy the specifications. For IKCs

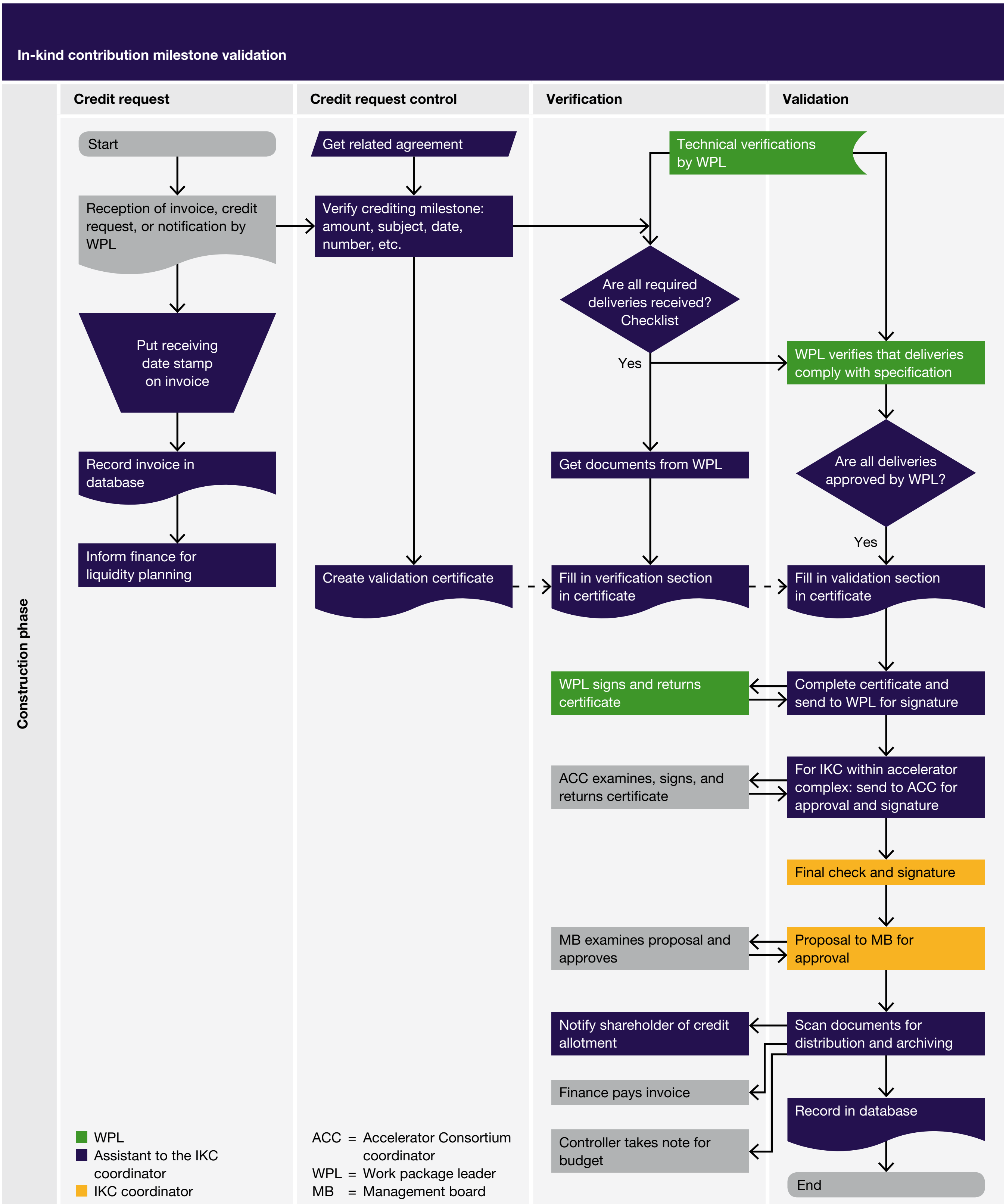


Figure 3 Flowchart of milestone validation process

related to the accelerator complex, the approval from the Accelerator Consortium coordinator (ACC) is necessary as a final step.

The IKC office supports this process by issuing a certificate to be signed by the WPL (and the ACC when applicable) and by archiving all necessary documents.

Work package leaders play an essential role in this process. In a first step, they verify that all of the requested documents and parts are delivered. In a second step, they make sure that the deliveries satisfy the specifications.

Each milestone validation must then be approved by the European XFEL Management Board and recorded in the database. This information is used later by the Finance and Controlling group for budgetary purposes.

Progress of IKC contracts

In 2011, the production phase started for many IKCs. Prototypes and some major components were manufactured, main contracts to subcontractors for large equipment were concluded, and raw materials were procured.

To follow up on IKC activities and strengthen relationships, the IKC coordinator visited several contributors (Table 4).

Abbreviation	Institute	Contributions to
BINP	Budker Institute of Nuclear Physics (BINP) of SB RAS in Novosibirsk, Russia	Cold vacuum (WP08) AMTF (WP10) Warm magnets (WP12) Cryogenics for the linac (WP13) Warm vacuum (WP19)
NIIEFA	D.V. Efremov Scientific Research Institute of Electrophysical Apparatus in St. Petersburg, Russia	Warm magnets (WP12)
NCBJ	National Centre for Nuclear Research (NCBJ) in Świerk, Poland	HOM couplers and beamline absorbers (WP06)
IFJ-PAN	Institute of Nuclear Physics of the Polish Academy of Sciences in Kraków, Poland	Tests in AMTF (WP10) Tests of cold magnets (WP11)
WUT	Wrocław University of Technology in Wrocław, Poland	Cryogenic equipment for AMTF (WP10)
IRFU	Institut de Recherche sur les lois Fondamentales de l'Univers of the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) in Saclay, France	Assembly of accelerator modules (WP03) Cavity string assembly (WP09)

Table 4 IKC contributors visited by the IKC coordinator in 2011

During these visits, he observed significant achievements demonstrating the strong commitment of the partner institutes to the European XFEL project. The infrastructure required for the realization of the IKCs had been installed, including highly sophisticated equipment and special tooling. The first prototypes were constructed, and acceptance tests showed promising results.

Significant achievements in 2011 are shown in Figures 4 through 11.

Significant achievements demonstrating the strong support of the partner institutes were observed. The necessary infrastructure had been installed, including highly sophisticated equipment and special tooling.

Figure 4 Manufacturing by WUT-WTP of the helium transfer line for AMTF

Figure 5 Mobile support by BINP for cryomodule testing in the AMTF hall

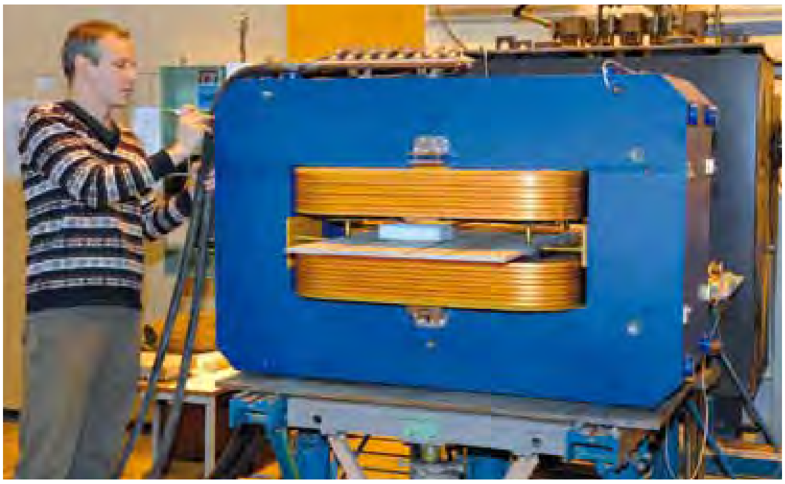


Figure 6 Control of a dipole magnet type XBB at NIIEFA

Figure 7 Fiducialization of a quadrupole magnet by MSL Stockholm

Figure 8 Prototypes of chamber and ceramics of the beamline absorber by NCBJ

Figure 9 First assembly at CEA (IRFU): cavity string in clean room ISO4 and attached to the supporting structure with helium lines

Figure 10 Pre-series prototype of a 5 m undulator segment by CELLS being examined in the European XFEL undulator hall

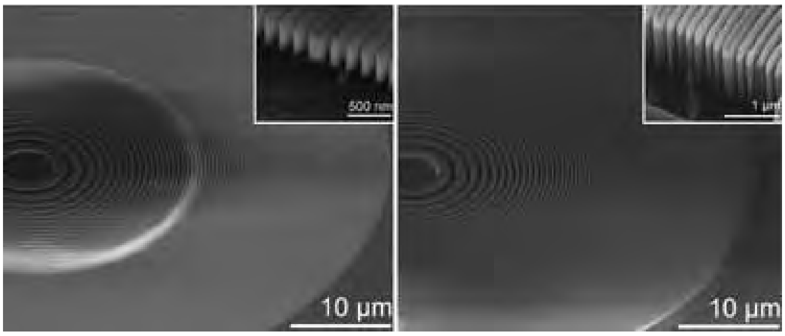


Figure 11 Prototypes of tungsten zone plate by KTH Royal Institute of Technology in Stockholm (images © KTH Stockholm)

Activity forecast for 2012

In 2012, the allocation of most of the IKCs from the remaining proposals is expected. In addition, a significant number of milestones should be achieved for the ongoing IKCs. Finally, as the result of six contributions, the AMTF facility should be completed and ready for operation. The first components of the accelerator complex should be delivered by the end of 2012. ■

Group members
Brunhilde van Hees, Serge Prat (group leader), and Martin Hagitte

ACCELERATOR CONSORTIUM

The accelerator complex of the European XFEL is being constructed by an international consortium under the leadership of Deutsches Elektronen-Synchrotron (DESY). Seventeen institutes are contributing to the construction of the superconducting accelerator, the subsequent transport systems for the 17.5 GeV electron beam, and their comprehensive infrastructure. In 2011, the first components were delivered and the boring of the accelerator tunnel was completed. Installation of the technical infrastructure for the tunnel will begin in the first quarter of 2012.

Additional funds allow confirming 17.5 GeV

One year ago, reducing the electron beam energy of the European XFEL from 17.5 GeV to 14 GeV was discussed at length. In principle, better electron properties would make it possible to achieve the light properties originally foreseen for the European XFEL at lower electron energies. Carefully conducted simulations showed that a linear accelerator shortened by 20 of the foreseen 100 accelerator modules would still be capable of achieving all of the project goals. These considerations were made in the event that the funds for the construction of a 17.5 GeV accelerator could not be made available.

In mid-2011, the German and Russian delegates of the European XFEL Council announced an initiative to obtain additional funding from the shareholders in order to enable the full 17.5 GeV “startup” configuration to be realized. As the detailed studies of the previous year corroborated, the 17.5 GeV configuration would allow an optimized working range of the European XFEL extended to short wavelengths, which would even better meet the needs of future users. The initiative was followed by the immediate decision that all accelerator components would be procured in accordance with the number of items needed for the 17.5 GeV startup configuration and that the construction of the accelerator would follow the original plan.

Accelerator Consortium

While the overall coordination of the facility, as well as the design and construction of photon beamlines and scientific instruments, is the responsibility of European XFEL, the accelerator complex is being built by the Accelerator Consortium, which is currently made up of 17 institutes. A project team led by DESY manages all consortium activities (Figure 1). The delivery of the first components is the result of many tasks performed by the consortium institutes and European XFEL groups. Prototypes are currently being tested at the participating institutes or on the DESY site. Regular visits to manufacturers—and the exchange of knowledge and information in the context of work meetings—determine the daily life of many partners. Virtually all major contracts for manufacturing the accelerator components have been awarded. Recently, all activities related to the construction of the accelerator complex were assigned to the respective institutes. The project team has been defined and its members are now cooperating closely.

The accelerator of the European XFEL is being assembled out of a large number of superconducting accelerator modules contributed by several partners. Other institutes contribute to the warm accelerator sections, accelerator controls, or infrastructure.

The procurement of technically sophisticated components such as radio frequency transmitters, as well as special beam diagnostics elements, is made possible by the strong commitment of technical experts and procurement specialists. Tendering and contracting are realized in close cooperations that sometimes last several months. They are followed by contract supervision, which in some cases may even extend until 2014. Long manufacturing times are not uncommon for large-series orders. Many orders that are associated with the accelerator infrastructure are carried out on a shorter time scale, however. In the Accelerator Module Test Facility (AMTF) area at DESY, the installation of energy supply, cooling, and air conditioning systems has started. Many tenders have been launched and contracts awarded for the equipment of the accelerator tunnel. This equipment ranges from lighting and cable trays, to security and communication technology, to tunnel vehicles.

Figure 1 Accelerator Consortium Board during a visit to the European XFEL construction site

First components

The accelerator of the European XFEL is being assembled out of a large number of superconducting accelerator modules contributed by several partners. Other institutes contribute to the warm accelerator sections (beamline vacuum system, beam transport magnets, and electron beam diagnostics), accelerator controls (including synchronization, timing, and feedback systems), or infrastructure (cryogenic installations and magnet power supplies).

One major challenge is the assembly of the 100 accelerator modules, which is due to start at the end of 2012. Small and large series of up to 800 identical components must be provided on schedule and with the appropriate quality assurance at seven different production sites.

One major challenge is the assembly of the 100 accelerator modules, which is due to start at the end of 2012. Small and large series of up to 800 identical components must be provided on schedule and with the appropriate quality assurance by DESY; Institut de Recherche sur les lois Fondamentales de l'Univers (IRFU) of the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) in Saclay, France; Laboratoire de l'Accélérateur Linéaire (LAL) in Orsay, France; Istituto Nazionale di Fisica Nucleare (INFN) in Milano, Italy; the National Centre for Nuclear Research (NCBJ) in Świerk, Poland; Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) in Madrid, Spain; and Budker Institute of Nuclear Physics (BINP) of the Siberian Branch of the Russian Academy of Sciences (SB RAS) in Novosibirsk, Russia. Over a period of about two years, work will be carried out with small buffers using "just in time" production cycles. Critical components, such as the accelerating

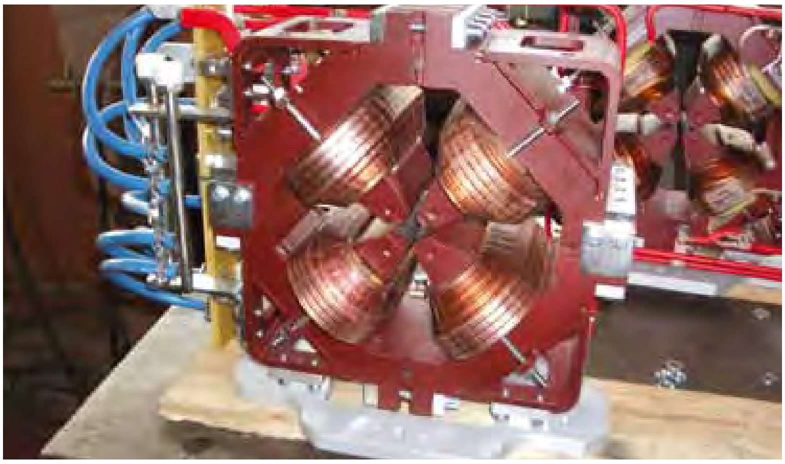


Figure 2 Batch of quadrupoles for the undulator beamline ready for shipment at BINP

structures themselves, will be released for installation only after elaborate tests. In other cases, predelivery inspection at the manufacturer is sufficient. The actual assembly is done in Saclay, followed by the final test in the DESY AMTF. Teams from the participating institutes will supervise the work.

Superconducting cavities can be seen as a kind of trademark for the accelerator of the European XFEL. The contracts for the production were placed in 2010. Two experienced companies are now close to completing the installation of the infrastructure needed for the large-series production. The first so-called “reference cavities” were delivered at the end of 2011. After delivery is completed, DESY will take care of the initial surface preparation and cold gradient test. Next, the cavities that pass the tests will be used for the commissioning of the vendor infrastructure. Series cavities are expected to be delivered in early summer 2012.

The procurement of cryostats (that is, the cryogenic part and outer shell of the accelerator module) was started in the fall of 2010. After negotiations with vendors, contracts were placed at the beginning of 2011. Based on prototypes built in 2009 and 2010, two companies are taking part in the production. The first cryostats will be delivered in spring 2012, so the assembly of the first accelerator modules can start as scheduled.

Superconducting cavities can be seen as a kind of trademark for the accelerator of the European XFEL. Two experienced companies are now close to completing the installation of the infrastructure needed for the large-series production.

The series production of about 700 electromagnets of over 20 different types is in full swing at the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA) in St. Petersburg, Russia. The first of the very challenging bunch compressor chicane dipoles has been produced and will now undergo a tedious “shimming” procedure to eliminate inhomogeneities in its magnetic field and ensure that it reaches the demanding field quality specifications. BINP has already produced almost all required focusing quadrupoles for the undulator beamlines (Figure 2). The magnets are now being measured and “fiducialized” (that is, their magnetic centerline position is being transferred to external fiducials) at Stockholm University in Sweden before being delivered to DESY for the final assembly in the undulator intersections.

The design of the vacuum system is progressing as planned with contributions from BINP and DESY. Series production items (for example, pumps, flanges, and bellows) have been specified and are in the process of being ordered.

Figure 3 Beam position monitor (BPM) for the European XFEL
Left top Body of a cold-button BPM. The beam position is derived from the signal of four electrodes that couple to the electromagnetic field excited by a bunch passing through the BPM.
Left bottom Single electrode
Right Complete assembly of a cold quadrupole (only the helium vessel is visible) and a BPM after assembly and cleaning in the cleanroom. This is the first unit to be delivered to Saclay for installation into the first European XFEL pre-series accelerator module.

The design and production of the beam dumps is the responsibility of the Institute for High Energy Physics (IHEP) in Protvino, Russia. All six beam dumps passed production readiness reviews in 2011. The production process is now being set up.

Electron beam diagnostics devices

The electron beam diagnostics system is crucial to the successful operation of the European XFEL. A wealth of electron beam properties must be measured and controlled along the 3 km long beam path from the electron gun to the beam dumps. The necessary diagnostic devices are developed by several members of the consortium and are mostly tested under real operating conditions at the Free-Electron Laser in Hamburg (FLASH).

Bunch charge
The beam charge will be measured at about 30 positions in the accelerator using toroids. The readout electronics has been improved to resolve smaller bunch charges according to the revised parameter set of the facility. Given that the toroids will be used to compare the transported charge at adjacent stations, they will also be part of the machine protection system. The multiple bunch pattern possibilities at the European XFEL pose an additional challenge to developers.

Even better resolution can be achieved with a novel device based on electromagnetic field excitation in a resonant structure. This device will measure the “dark current”, which consists of unwanted accelerated particles outside the electron bunch.

Even better resolution can be achieved with a novel device based on electromagnetic field excitation in a resonant structure. This device is foreseen to measure the so-called “dark current”, which consists of unwanted accelerated particles outside the electron bunch. The device can also resolve bunch charges down to a few femtocoulombs, as tests with a prototype installed at the Photo Injector Test Facility (PITZ) at DESY in Zeuthen have shown.

Transverse bunch properties
The centroid position of each bunch can be monitored at about 400 locations. Four different types of beam position monitors (BPMs) will be used, depending on the required accuracy (Figure 3). Collaborating scientists from CEA, DESY, and the Paul Scherrer Institut (PSI) in Villigen, Switzerland, have been developing the system since 2007. The system now shows a single-bunch resolution of almost 1 μm in test measurements. The series production of BPM pickups has started, while the electronics will undergo another pre-series cycle before going into production.

Figure 4 Prototype of the combination of a wire scanner and an optical transition radiation screen

Transverse bunch profiles are an important measure used to determine the correct size and optics properties of the electron beam. At the European XFEL, the bunch profiles will be measured at about 40 screen stations and 12 wire scanner stations. Some screens will be mounted in such a way that single bunches in a bunch train can be kicked out of the nominal beam axis to hit the screen, thereby allowing online monitoring of the beam properties. Wires are constructed to move fast enough to scan sufficient bunches within one bunch train in order to reconstruct the average bunch profile. Prototypes of these systems have been built to investigate the sophisticated mechanics and the imaging optics concepts.

A series of beam tests at Mainz Microtron (MAMI) and FLASH was devoted to solving the problem of coherent optical transition radiation (COTR) production in the screen material. COTR will affect all

Figure 5 View of the new AMTF, which will be used to test all 800 superconducting cavities and all 100 accelerator modules. For two years, this hall will be the home of a team of experts from different consortium institutes.

measurements that make use of screens. However, a proper choice of screen material and observation optics can probably reduce the effects of COTR to a tolerable level (Figure 4).

The superconducting accelerator of the European XFEL requires a suitable cooling supply. During the acceptance tests, both the individual accelerating structures and the completed accelerator modules need to be cooled to 2 K.

Longitudinal bunch properties
Information about the longitudinal bunch properties can be derived in several ways. The beam energy can be measured with standard BPMs at places in the machine where the beam position depends on the beam energy (dispersive sections). The longitudinal position of the bunch with respect to a reference clock signal—the beam arrival time—can be monitored by overlaying the electric field generated by a beam pickup with the laser field of the timing laser and observing the modulations in the laser pulse amplitude. These beam arrival-time monitors (BAMs) have been developed since 2008 and are now in routine operation at FLASH. When implemented in a feedback loop, they allow the reduction of the otherwise unavoidable arrival-time jitter.

The longitudinal bunch profile is measured in the injector and behind the second and third bunch compressor with the help of a transverse deflecting structure (TDS). This device gives a time-varying transverse kick to the bunch. The projection of the time axis and one transverse

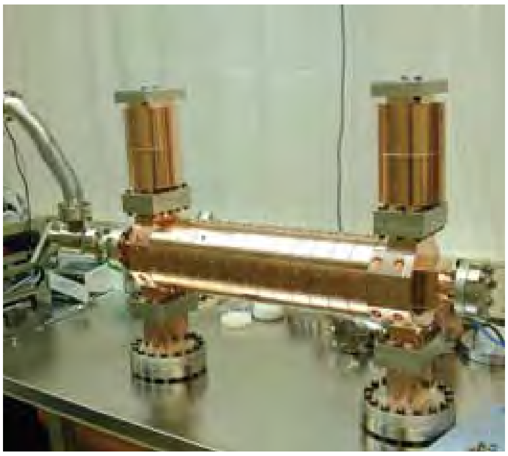


Figure 6 Pre-series transverse deflecting structure as delivered to PITZ

Figure 7 The former DESY HERA refrigeration plant is being remodeled and modernized for the European XFEL.

axis (perpendicular to the kick direction) of the beam can then be observed on a subsequent screen. This projection provides information about the variation of the bunch width along its length and, in combination with a dispersive section, about variations of the energy along the bunch. The TDS is being developed and produced at the Institute for Nuclear Research (INR) of the Russian Academy of Sciences (RAS) in Troitsk, Russia. A first pre-series structure has been delivered to PITZ and will be used for longitudinal bunch profile measurements (Figure 6).

Cryogenic infrastructure

As a superconducting accelerator, the European XFEL requires a suitable cooling supply. During the acceptance tests in the AMTF—which will be performed by DESY and the Henryk Niewodniczański Institute of Nuclear Physics (IFJ-PAN) of the Polish Academy of Sciences in Kraków, Poland—both the individual accelerating structures and the completed accelerator modules need to be cooled to 2 K. For this purpose, the existing refrigeration plant at DESY must be rebuilt and modernized for European XFEL operation. A corresponding order has now been placed with industry. In addition, a number of transfer lines to transport the cold helium are being manufactured and installed together with sophisticated distribution boxes. Contributions in the field of refrigeration technology come from BINP, DESY, IHEP, and Wroclaw University of Technology. ■

04

PHOTON BEAM SYSTEMS

European XFEL scientists design the arrays of magnets in which the X-ray pulses are produced, model and improve the X-ray beams, build optical elements that transport them to the instruments, and develop diagnostics devices to monitor the X-ray pulses.

UNDULATOR SYSTEMS

Undulator systems play an important role for the European XFEL. These long arrays of magnets force the electrons to follow a slalom trajectory, inducing them to emit intense pulses of radiation, which, under appropriate conditions, are amplified through the self-amplified spontaneous emission (SASE) process. The large and demanding devices, which will be built in close collaboration with European industry, are being designed by the Undulator Systems group.

In the startup phase of the European XFEL, there will be three undulator systems, named SASE1, SASE2, and SASE3. For reasons of technical feasibility, each undulator system needs to be subdivided. A length of 5 m was found to be the best for each individual undulator segment, or section, which is followed by a 1.1 m long intersection. Such a unit of section and intersection is called an undulator cell. Every intersection comprises a quadrupole magnet on a moving support, a beam position monitor, a phase shifter, air coil correctors, a radiation absorber, and a vacuum pump.

SASE1 and SASE2 comprise 35 segments each, while SASE3 is divided into 21 segments. Their combined magnetic length is 455 m. Beginning in 2005, the technology for these systems was developed as part of the PETRA III project at Deutsches Elektronen-Synchrotron (DESY). In 2007, the Pre-XFEL project joined this effort. Since then, the technology has proven itself in thorough tests. Following the European XFEL design, which originated from the DESY collaboration, the hardware for the undulator segments will be built in close collaboration with European industry. The construction of four prototypes with an undulator period length (λ_0) of 40 mm (U40s) and two prototypes with λ_0 = 68 mm (U68s) began in 2010 and was completed by mid-2011. The construction phase was followed by a six-month test and evaluation phase, which provided a last chance to implement design changes and improvements. All activities prepared for serial production, which will begin in 2012.

Status of procurement

The procurement of all undulator segments for the European XFEL began in 2010. It was a two-step process: call for tender and request for quotation.

The first step started at the end of 2010 with the call for tender. Vendors fulfilling criteria were pre-selected, based on their capabilities and experience. These vendors were invited to bid on the six pre-series prototypes—four U40s (SASE1 and SASE2) and two U68s (SASE3)—and were given the chance to qualify themselves by successfully building the prototypes. This approach was chosen to introduce vendors to European XFEL undulator technology, thereby enabling them to produce high-quality undulator segments on schedule and within budget. It turned out that the European market for this type of hardware was limited. Only three suppliers who fulfilled the requirements could be found.

The first step of the procurement process was completed in July 2011, when the last undulator prototype segment was delivered to European XFEL. The criteria for the ensuing evaluation were based on quality and production management, as well as device performance and tests made after delivery. All three vendors proved to be qualified.

In December 2011, the second step of the procurement process was started. A request for quotation was sent to the qualified vendors for the remaining 85 undulator segments. This step is critical, as it determines the time scale for the production of the undulator segments.

According to the overall European XFEL schedule, the production of all undulator segments is expected to take two years. Therefore, three measurement benches are needed to work in parallel.

Magnetic measurement lab

Industrial production is just the first part in the life cycle of an undulator segment. This life cycle also includes the measurement and tuning of the magnetic properties, followed by the full commissioning, the installation in the tunnel, and eventually the actual operation. The critical tasks of undulator measurement and tuning can be performed only at the European XFEL facility itself, where it is possible to verify that the hardware is in full compliance with the specifications.

For magnetic measurements and tuning, substantial lab space is required. Because there is no archetype for such a magnetic measurement lab, its size and capacity was estimated, based on experience at the Free-Electron Laser in Hamburg (FLASH) and PETRA III at DESY, taking into account learning and training effects. This experience led to the basic assumption that the measurement and tuning of an undulator segment would, on average, take about three weeks. According to the overall European XFEL schedule, the production of all undulator segments is expected to take a total of two years. Therefore, three measurement benches are needed to work in parallel. Each of the benches requires a measurement room of about 70 m^2, which is temperature-stabilized to ± 0.1°C.

Fortunately, about 1 100 m^2 of lab space, accessible with a 20-tonne crane, became available in DESY Building 36 (Figure 1). One room with a measurement bench, called XFEL#1, was built in 2008–2009 as part of the Pre-XFEL project and is fully operational. Two more measurement rooms were planned and built in 2010. They were then commissioned during the first half of 2011. The measurement benches were installed and mechanically commissioned in September 2011. They will become fully operational in early 2012.

Outside the magnetic measurement rooms, a significant amount of lab space is needed for the commissioning of the hardware, for the assembly of other components, such as intersections, and for various tests and test setups, as well as for sufficient buffer storage space for incoming and outgoing undulator segments.

First European XFEL prototype

A long-term collaboration between the Institute of High Energy Physics (IHEP) in Beijing and European XFEL began in 2008. Within this collaboration, the very first dedicated prototype undulator segment for the European XFEL facility was built in 2009–2010 using European XFEL technology. After extensive measurements and tuning at IHEP, the prototype arrived in Hamburg at the end of February 2011. Although it was made in China using Chinese magnet materials, it includes key European XFEL-type components, such as spindles and guidance-and-control systems. Unfortunately, it was built with the old SASE2 period length of 48 mm, which was the valid design parameter when construction began at the end of 2009. Nevertheless, the prototype

Figure 1 European XFEL magnetic lab in Building 36 with around 1100 m^2 of lab area in December 2011. Five pre-series undulator segments are standing on the left and in the foreground. The three magnetic measurement rooms are in the middle. Room XFEL#1 in the rear is fully operational. Rooms XFEL#2 and XFEL#3 in the foreground (in European XFEL colours) will become operational in spring 2012.

was the first undulator segment available at the European XFEL, and was extensively used to test and develop magnetic measurement techniques.

In January 2011, a follow-up project was started between IHEP and European XFEL. A new magnetic structure with SASE1 and SASE2 parameters, λ_0 = 40 mm, was built and replaced with the U48 structure, thus enabling the undulator segment to be used in SASE1 or SASE2. This work was finished in November. The objective is to use this undulator segment together with the other U40s. As of December 2011, there are five U40s and two U68s at the European XFEL.

Parallel to the hardware construction, magnetic measurement techniques were developed and refined. The ultimate goal is to have tools at hand that allow for fast measurements and tuning. Development of fast and efficient techniques for tuning and error correction is one of the key issues for serial production.

Magnetic measurements and tuning

Parallel to the hardware construction, magnetic measurement techniques were developed and refined. The ultimate goal is to have tools at hand that allow for fast measurements and tuning. Development of fast and efficient techniques for tuning and error correction is one of the key issues for serial production.

Figure 2 Martin Knoll (left) and Manfred Gaida (right) tune the pole heights of the first U40. For tuning, the gap is fully opened, so the fourfold micrometre dial gauge can be inserted. With this device, the pole height and tilt of the lower pole and the corresponding upper pole can be changed with an accuracy of ± 1 µm, if needed. One full tuning step requires about one and a half to two days.

The tuning is facilitated by an adequate design of the magnet structures and its support, based on previous experience with the undulators for FLASH and PETRA III. Each pole can be individually shifted by ± 0.4 mm, tilted by ± 4 mrad, or both to compensate field errors in both transverse beam directions. In this way, the exact shifts and tilts of all poles (example: 248 poles for an U40) are fine-tuned. Appropriate measurement techniques and algorithms have been developed and are being further refined. Starting with accurate field data, field errors are determined and assigned to each pole.

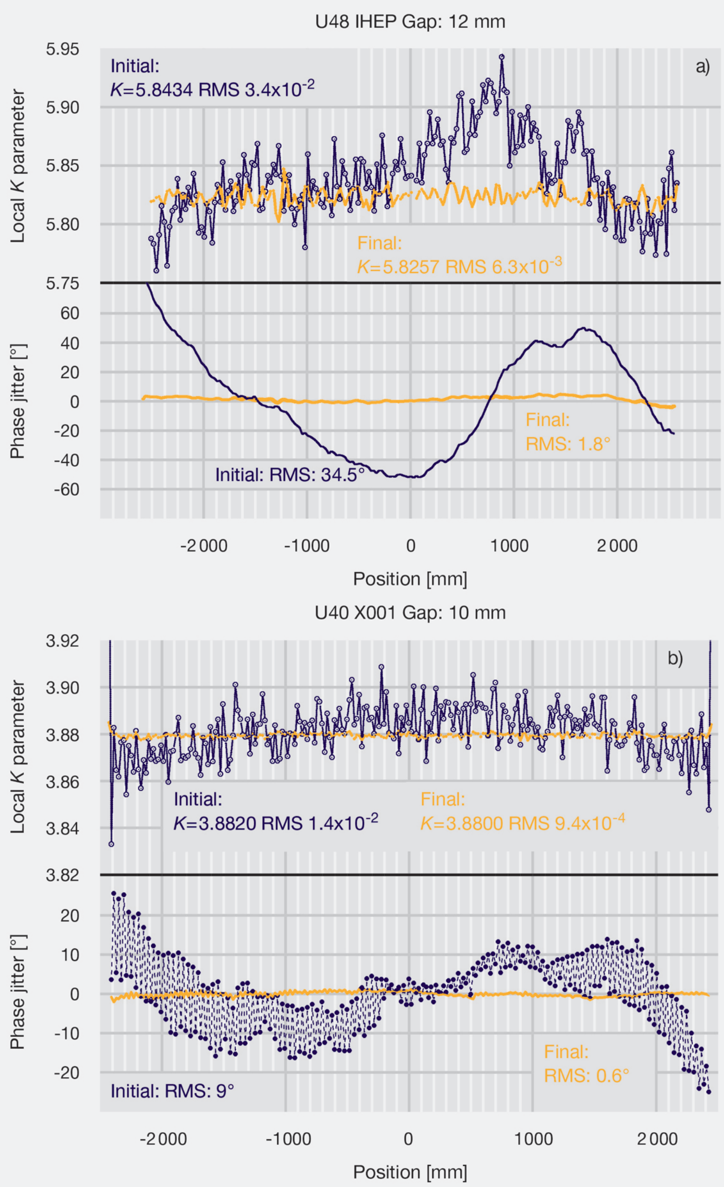


Figure 3 Measurement results showing the effect of the pole tuning: a) IHEP U48 and b) U40 prototype. The violet curves show the status prior to tuning. Errors are determined by material and assembly imperfections. The orange curves show the status after tuning. Each pole is shifted by not more than ± 100 µm. The objective of the tuning procedure is to tune each pole to the same K parameter. Consequently, the phase jitter is reduced.

The pole shifts and tilts to correct these errors are calculated, and a pole tuning list is generated. Using this list, the poles have to be tuned manually (Figure 2). This method allows for close-to-perfect field properties in the operational gap range. Figure 2 gives an impression of how the pole tuning is done. A fourfold micrometre dial gauge is inserted in the open gap of the undulator segment. The dials allow the simultaneous tuning of the top and bottom pole of a half period with an accuracy of about ± 1 μm. Each pole is tuned according to the tuning list.

Figure 3 demonstrates the effect of the magnetic tuning. Results of the Chinese U48, as measured at IHEP in Beijing, are shown in Figure 3a). Corresponding data for the first U40, measured at European XFEL, are shown in Figure 3b). The first step of the tuning algorithm is to define a target value for the *K* parameter. The tuning objective is to adjust the local *K* parameter of each half period to this value, and thus to keep it constant over the whole structure. This tuning can be nicely seen by comparing the initial and final results. The scatter of the local *K* parameter is reduced dramatically. The upper part of Figure 3a) shows the *K* parameter of 200 of 208 bulk poles for the U48. The upper part of Figure 3b) shows the *K* parameter of 240 of 248 bulk poles for the U40. In both cases, “bulk” means full poles, thus excluding the poles near the ends. The reduction of the scatter of the local *K* parameters is obvious. The phase jitter is reduced to very small values: 1.8° for the U48 and 0.6° for the U40.

Meanwhile, the tuning method applied on the U40 has been further improved, as compared to the U48. Now all poles are adjusted by an algorithm, which allows for tuning the whole structure in one single tuning step. This single-step tuning will result in a significant reduction of the measurement and tuning effort, which is the ultimate objective.

Meanwhile, the tuning method applied on the U40 has been further improved, as compared to the U48. Now all poles, including the poles of the end sections, are adjusted by the algorithm. The algorithm allows for tuning the whole structure in one single tuning step, starting with only one initial measurement. This single-step tuning will result in a significant reduction of the measurement and tuning effort, which is the ultimate objective. For the U40 prototype, whose results are shown in Figure 3, this objective was only partially reached. After the first tuning step, about 60 poles in the centre of the structure needed a second adjustment step for reasons that are not yet clear. But, for the remaining 180 poles of the structure, single-step tuning worked well. This raises hopes that the tuning method can be further improved in the future.

Further plans

All undulator system plans are driven by the time schedule of the project.

For 2012, these plans include:

- Starting production of the remaining 85 undulator segments in early 2012. The corresponding request for quotation was sent out at the end of 2011.
- Commissioning the two new benches, making all three benches in the magnetic lab fully operational.
- Hiring and training the staff to operate the benches and do the tuning.
- Receiving delivery of the first serial undulator segments in fall 2012.
- Ramping up the throughput of the magnetic measurements facility to keep pace with production.

Group members
Maik Neumann, Wolfgang Tscheu, Suren Karabekyan, Martin Knoll, Maike Röhling, Georg Deron, Yuhui Li, Uwe Englisch, Andreas Beckmann, Abhishek Desai (not shown), Manfred Gaida (not shown), Axel Liebram (not shown), Joachim Pflüger (group leader, not shown), and Xuetao Wang (not shown)

SIMULATION OF PHOTON FIELDS

The Simulation of Photon Fields (SPF) group develops novel schemes to improve the characteristics of the European XFEL in order to ensure the best X-ray free-electron laser (FEL) facility in a quickly developing global scientific environment. The SPF group also models the properties of the photon beams produced by the facility's undulators, simulating spontaneous radiation (SR) and X-ray FEL radiation to facilitate beamline optics design, photon beam-based diagnostics, and some scientific applications.

Cooperation with DESY

In 2011, the SPF group continued its activities in the framework of a very fruitful collaboration with Vitali Kocharyan and Evgeni Saldin of Deutsches Elektronen-Synchrotron (DESY). This extended group investigated several schemes for soft X-ray polarization control, a feature that is useful, for example, to reveal the structure of magnetic domains in samples.

The extended group also cooperated with Winfried Decking and Igor Zagorodnov, also at DESY, to adapt a previously investigated method used to produce radiation with frequencies in the terahertz (THz) range, and to propagate the THz radiation to the SASE2 beamline. These results are important in view of pump-probe experiments in which THz and X-ray radiation are used to perturb and probe the samples.

In addition, the extended group dedicated considerable attention to implementations of hard X-ray self-seeding schemes based on single-crystal monochromators. Self-seeding schemes make it possible to obtain very-narrow-bandwidth radiation compared to the self-amplified spontaneous emission (SASE) mode of operation and provide options for improving other key parameters of an X-ray FEL facility.

Soft X-ray polarization control

Among different possibilities for polarization control that the collaboration with Kocharyan and Saldin analysed was a simple and flexible method for filtering out the linearly polarized background produced by the main SASE FEL. In fact, highly circularly polarized radiation can be obtained from a helical afterburner tuned at the fundamental harmonic of the main SASE3 undulator. However, in this case, the linearly polarized emission generated by SASE3 must be separated from the circularly polarized emission produced by the afterburner. The method developed by the collaboration achieves this separation, effectively enabling scientists to work at the fundamental harmonic of SASE3, thereby extending the spectral range of the circularly polarized light to longer wavelengths. These wavelengths are important for experiments comprising the spectral range of the L-edges of 3d transition metals. The devised scheme is naturally independent of the choice of afterburner technology.

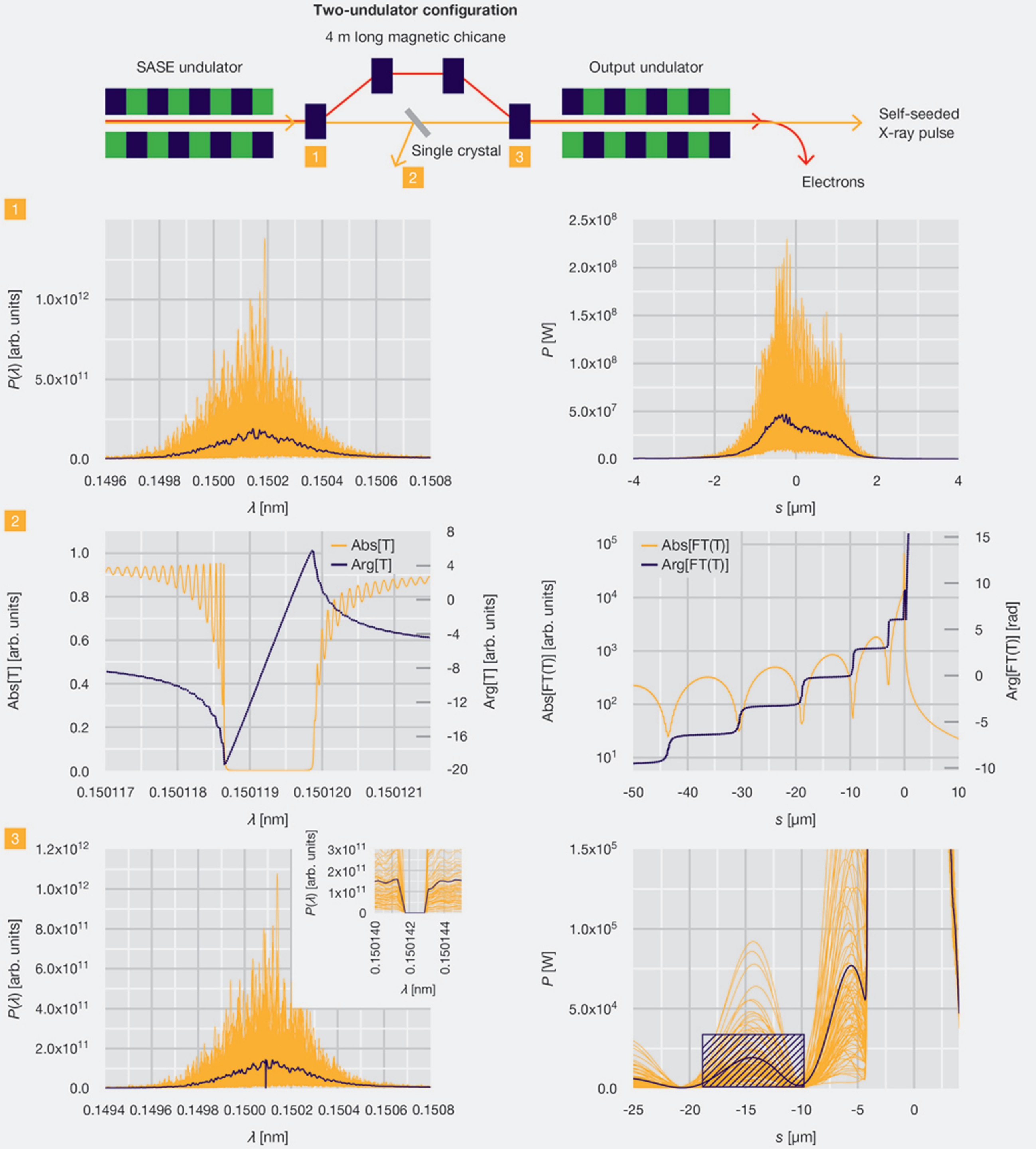
Production and propagation of THz radiation

An issue addressed by the collaboration with Decking and Zagorodnov concerned the production and transport of THz radiation generated by the spent electron beam downstream of the SASE2 undulator in the electron beam dump area [1]. The collaboration's approach was to consider the problems of production and transport as being related. In fact, the THz output must propagate over a very long distance, at least 250 m, through the photon beam tunnel to the experiment hall, in order to reach the SASE2 X-ray hutches. In a previous work written in collaboration with Kocharyan and Saldin, the SPF group proposed to use an open beam waveguide, such as an iris guide, as a transmission line. This iris transmission line is composed of an array of metallic screens with circular holes in the middle. The collaboration adapted this method to the SASE2 line. To efficiently couple the radiation into the iris transmission line, generation of the THz radiation pulse can be performed directly within the iris guide. The line transporting the THz radiation to the SASE2 X-ray hutches introduces a path delay of about 20 m. To enable THz pump, X-ray probe experiments, the collaboration proposed exploiting the high repetition rate of pulses at the European XFEL to cope with the delay between THz and X-ray pulses. Their calculations showed that the maximally achievable field strength at the sample is very high, on the order of 1 V/Å.

The self-seeding technique based on a single-crystal monochromator allows the realization of single-mode X-ray FELs.

Self-seeding scheme based on single-crystal monochromator

To date, the most important result obtained by the collaboration with Kocharyan and Saldin remains the self-seeding technique based on a single-crystal monochromator, which allows the realization of single-mode X-ray FELs [2]. The method is based on the exploitation of a weak chicane placed after several SASE modules. The chicane washes out the electron beam microbunching produced in the first part of the undulator, introduces a short but tunable delay between electrons and photons, and allows for the insertion of a single crystal in Bragg transmission geometry in the X-ray path. The radiation pulse transmitted through the crystal was shown to exhibit a long monochromatic tail as a function of time. Part of it will be used for seeding and amplified in the second undulator part (Figure 1).



λ = wavelength s = coordinate along the photon pulse P = power T = transmission function FT = Fourier transformation Abs = modulus Arg = phase

Figure 1 Single-crystal monochromator principle
Left Frequency domain: The effect of the crystal can be modeled by multiplying the incident SASE field in the frequency domain (modulus and phase) by a proper transmission function (in the frequency domain).
Right Time domain: The effect of the crystal can be modeled by convolving the incident SASE field in the time domain (modulus and phase) with the Fourier transform of the transmission function.

The scheme was successfully tested at the beginning of 2012 at LCLS, and was shown to provide, as a by-product, a very convenient way of carrying out direct X-ray pulse length autocorrelation measurements as proposed in 2010 by the collaboration. This groundbreaking experiment opens up the possibility of implementing a number of new exciting applications, which were studied theoretically in 2010–2011 in the collaboration. The applications include doublet and multiplet generation by insertion of more crystals in a series (also allowing for the creation of a powerful pulse of coherent optical transition radiation); hard X-ray polarization control through the use of a phase-shifter crystal; and extension to hard X-rays by tuning part of the output radiator to the second harmonic of the fundamental, thus optimizing the bunching process at the second harmonic (Figure 2). Finally, it should be noted that hard X-ray self-seeding, coupled with proper post-saturation tapering, holds promise for the realization of very powerful X-ray FELs at the terawatt level, and that the single-crystal principle can be naturally extended to the soft X-ray case through the exploitation of a gas cell monochromator. This remains an interesting and simple alternative to self-seeding based on grating monochromatization.

The self-seeding scheme was successfully tested at LCLS. This groundbreaking experiment opens up the possibility of implementing a number of new exciting applications, which were studied theoretically in 2010–2011 in the collaboration.

Refining radiation simulation software

In 2011, the SPF group continued activities related to simulations of spontaneous radiation (SR) from the baseline European XFEL undulators. This SR defines the background signal for FEL measurements (and becomes increasingly important at higher harmonics), contributes to heat loading, and is used in photon-beam-based alignment (PBBA) procedures. The SPF group finished production of a collection of important routines from the Synchrotron Radiation Workshop (SRW) code, which was started in 2010. This result was obtained in cooperation with SRW author Oleg Chubar of Brookhaven National Laboratory (BNL) in the USA and involved a cooperation with Liubov Samoylova of the European XFEL X-Ray Optics and Beam Transport group, whose interests include the propagation of both spontaneous and FEL radiation wavefronts down the photon beamlines.

In August 2011, Ilya Agapov joined the SPF group. His expertise as a physicist, mathematician, and software developer quickly allowed the group to create a preliminary version of a software package supporting parallel runs on clusters. This package is essential to speed up calculations that would otherwise take too much time to complete.

The same technology also enables very efficient parallel runs of FEL radiation simulations using the Genesis code (Figures 3 and 4). The software package also includes an easy-to-use graphical user interface (GUI) that allows users to quickly set parameters, view simulation results, and control simulations through scripts.

The SPF group created a preliminary version of a software package supporting parallel runs on clusters. This package is essential to speed up calculations that would otherwise take too much time to complete.

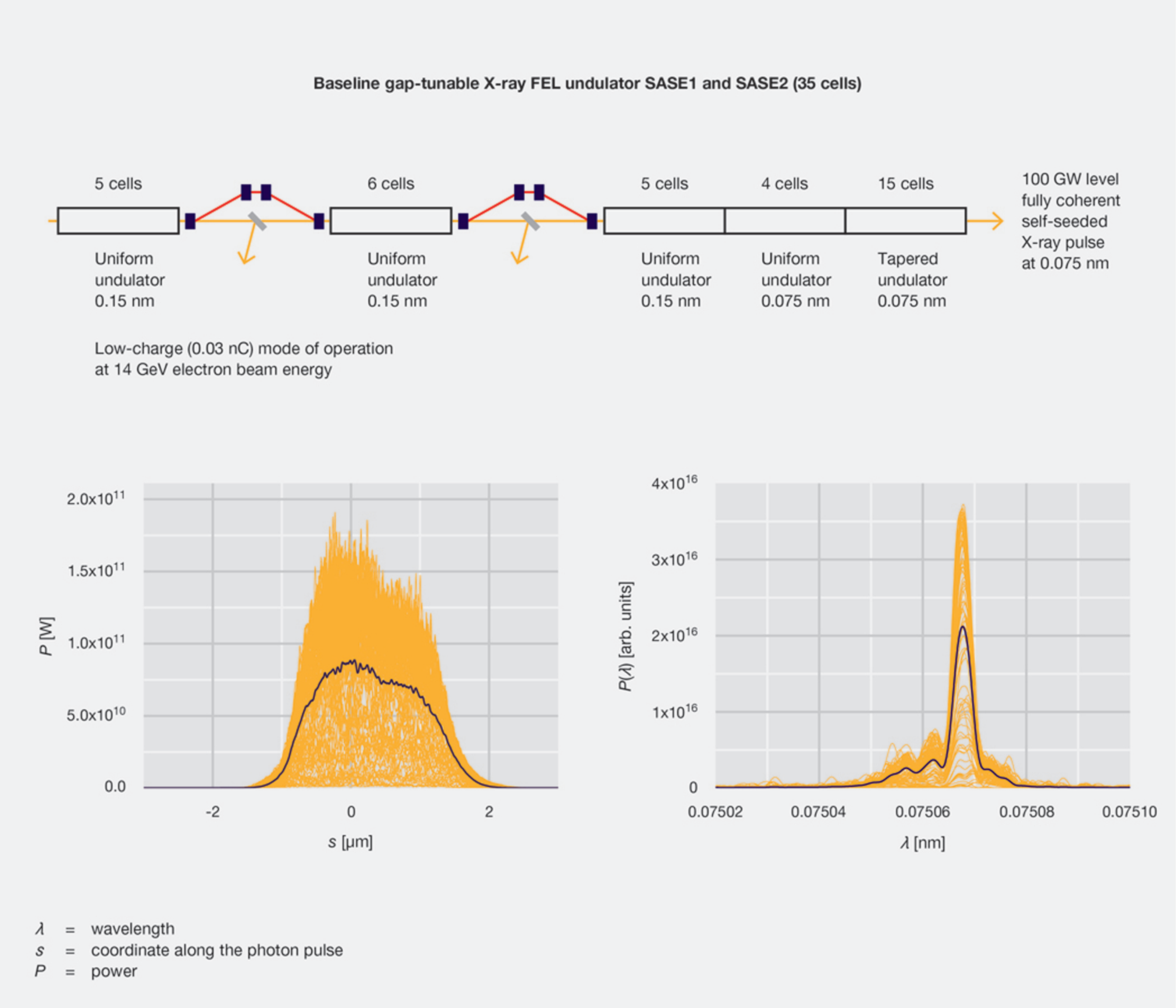


Figure 2 Nearly Fourier-limited X-ray pulses of around 100 GW can be obtained by combining self-seeding techniques, harmonic generation, and tapering.

A cooperation with Nikolay Smolyakov and Sergey Tomin of the National Research Centre Kurchatov Institute (NRC KI) in Russia on alternative routines for SR calculations, which began in 2010, continued in 2011 in the framework of the cooperation “Accelerators and Reactors in Western Europe (except CERN)”. The results of these efforts will be

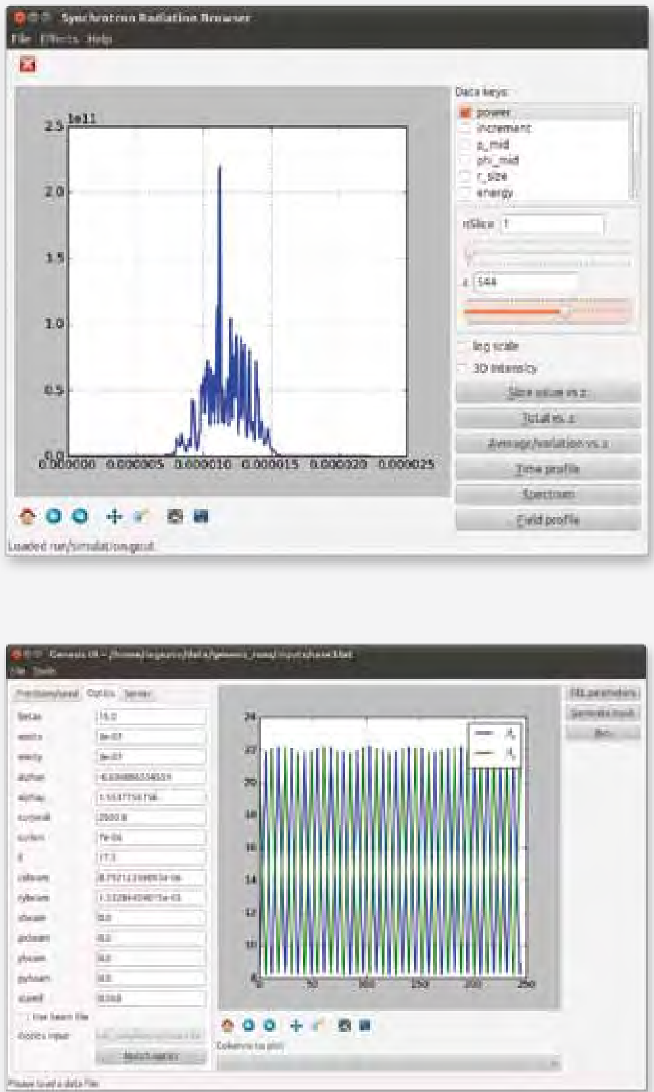


Figure 3 First example of calculations of FEL radiation using the SRW code with the new software package developed by Ilya Agapov. The package supports parallel runs on clusters, and includes a GUI for quick setting of parameters and viewing of simulation results. Python scripting capabilities are also enabled.

included in the SPF software package. The cooperation on PBBA diagnostics with the European XFEL X-Ray Photon Diagnostics group continued to investigate, in particular, a two-segment “kicker” scheme for determining the difference in the undulator *K* parameter between different segments.

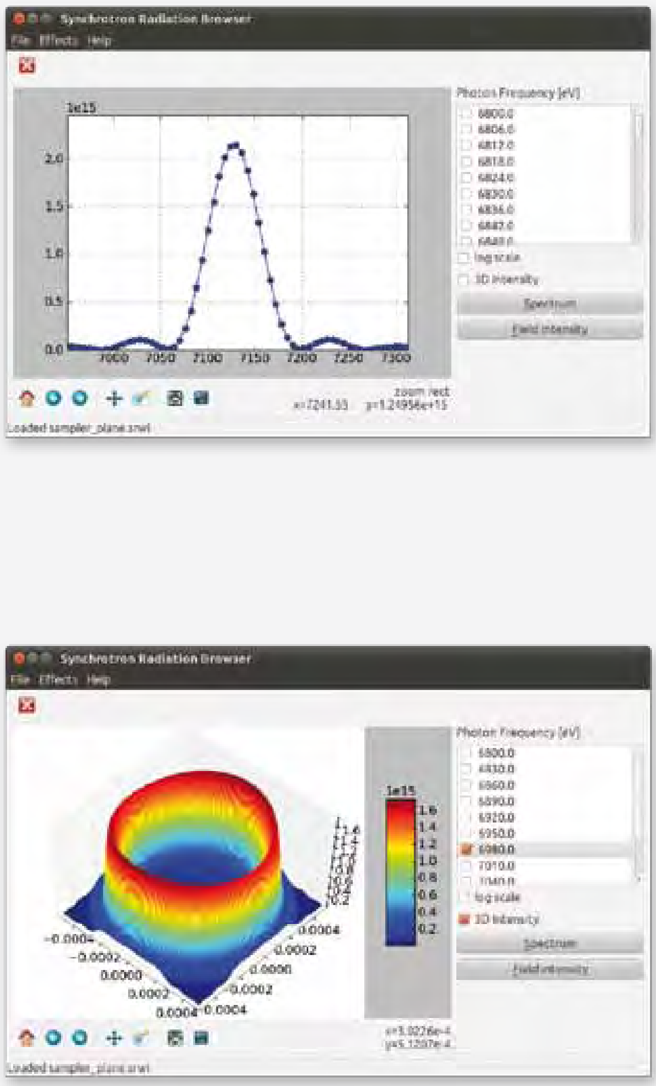


Figure 4 First example of calculations of spontaneous radiation using the SRW code with the new software package developed by Ilya Agapov.

Enabling new science

Finally, the SPF group pursues a fruitful cooperation with Nikolay Kabachnik from the Institute of Nuclear Physics at Moscow State University, Russia, who had already worked with the European XFEL Small Quantum System (SQS) instrument group. In 2011, this cooperation was enlarged to include the Single Particles, Clusters, and Biomolecules (SPB) instrument group and the SPF group, which took over coordination. The overall goal was to bring together different areas of investigation on the interaction between ultrabright, ultrashort pulses from X-ray FELs and matter in an environment where FEL physics knowledge is made available and can be exploited for the development of new science. This activity will be continued in 2012.

In 2012, the SPF group plans to deepen and broaden the research areas pioneered in 2010–2011. It will further push the development of its novel computer simulation package. Following the demonstration of single-crystal self-seeding, the group expects that the cooperation with DESY will play a leading role in the development of a self-seeding setup for the European XFEL.

Outlook for 2012

In 2012, the SPF group plans to deepen and broaden the research areas pioneered in 2010–2011. The group will further push the development of its novel computer simulation package, dealing with both spontaneous and FEL radiation, and perform cross-checks with the WAVE code developed at Helmholtz-Zentrum Berlin (HZB) by Michael Scheer. It will continue the collaboration with Chubar (BNL) and with Smolyakov and Tomin (NRC KI), mainly focusing its activities on the estimation of resolution and performance of PBBA methods. The SPF group will continue cooperating with Kocharyan and Saldin (DESY) to study novel upgrade possibilities of the baseline SASE beamlines at the European XFEL. The group will also continue its cooperation with Kabachnik and the SPB and SQS groups. Finally, following the demonstration of single-crystal self-seeding, the SPF group expects that the cooperation with DESY will play a leading role in the development of a self-seeding setup for the European XFEL.

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[1] Scheme for generating and transporting THz radiation to the X-ray experimental hall at the European XFEL
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Group members
Gianluca Geloni (group leader) and Ilya Agapov

X-RAY OPTICS AND BEAM TRANSPORT

To enable experiments at the European XFEL, the X-ray free-electron laser (FEL) beam must be transported from the undulators to the scientific instruments. On its way, unwanted radiation background of very high-energy bremsstrahlung and spontaneous radiation has to be removed. In some cases, a monochromator filters out a narrow band of wavelengths, and eventually the beam is prefocused into the experiment hall. The task of the X-Ray Optics and Beam Transport group is to design and build X-ray optical elements that can perform these tasks while withstanding the high power load during X-ray FEL pulse trains and preserving wavefront and timing properties.

Conceptual design of photon beamlines

The most important elements of the X-ray beam transport systems are ultraflat, 800 mm long, horizontally deflecting mirrors. They are used to offset the X-ray FEL beam from the background radiation and distribute it to the different experiment stations. The shape error specification for these mirrors is a peak-to-valley distance (the distance from the highest to the lowest point of the mirror surface) of 2 nm, a value that has not yet been reached for mirrors of this length. An R&D programme has been started that targets these specification goals through local correction of shape errors using piezoelectric actuators. It will also be possible to tune the spherical radius of some of the mirrors to focus the X-ray FEL beam at different locations.

The beam power density in the pulse trains can exceed 10 kW/mm^2. To minimize the effects of thermal heat load and beam damage, the first optical elements that intercept the X-ray FEL beam are located about 250 m from the undulators. On the mirrors, a grazing-angle geometry (0.06°–1.4°) distributes the power over a large surface, which further increases the damage resistivity.

The X-ray FEL energy bandwidth can be reduced by using cryogenically cooled silicon monochromators for the hard X-ray beamlines (photon energies of 3–24 keV). The two monochromator crystals will be mounted on a common rotatable and adjustable platform with rigorous stability requirements (artificial channel-cut). This arrangement reduces pointing errors arising from asynchronous angle vibrations of the two crystals against each other, which would lead to noticeable beam motions in the experiment hall. The hard X-ray monochromator is developed in collaboration with Argonne National Laboratory in Illinois.

For the soft X-ray experiments (photon energies of 0.25–3 keV), a grating monochromator is currently being developed with up to 500 mm long gratings and Fourier-limited pulse stretching.

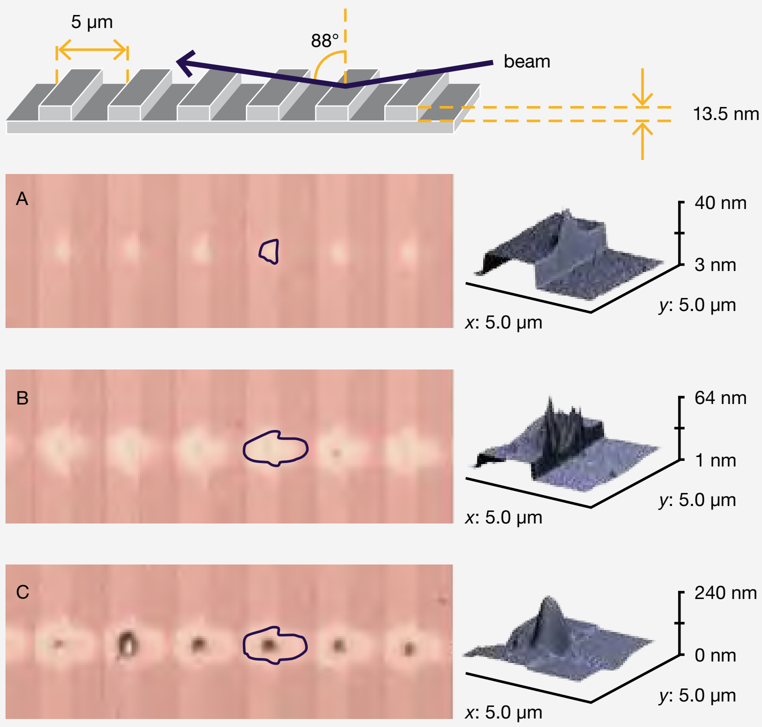

Figure 1 Damage on a grating structure measured at FLASH with 270 eV radiation.
Top Geometry with respect to the beam.
Left Pictures taken with an optical microscope after single FEL shots with different intensity levels.
Right Corresponding atomic force microscope (AFM) measurements (J. Gaudin et al., to be published in 2012).

The conceptual design report for the beam transport system was reviewed by an international advisory review team (ART) in April 2011 (see Chapter 7, “Organs and Committees”) and is available on the European XFEL website [1].

Avoiding damage to X-ray optics

Damage is an important boundary condition for the design of X-ray optics at the European XFEL. The 100 fs X-ray pulses can cause instantaneous “single-shot damage”. Because the time scales involved are very short, ordinary thermal transport can be neglected and the damage threshold is constant over a wide range of incidence angles. This situation changes, however, for incidence angles below the critical angle when total external reflection of the X-rays is reached. The optics are then more resistant to the X-ray beam, and the damage threshold is increased. A special situation occurs when total-reflection geometry and normal (perpendicular) incidence are mixed on short length scales, as is the case for the nanostructured gratings used for the soft X-ray monochromator.

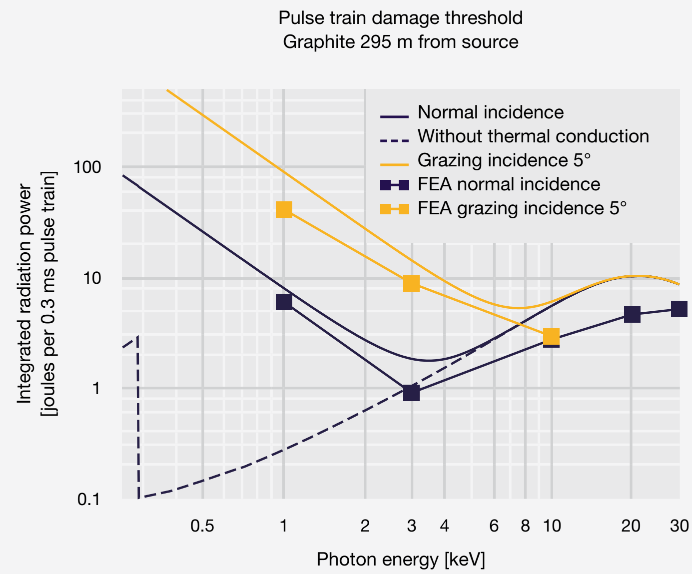

Figure 2 Thermal analysis of the pulse train damage threshold of a water-cooled graphite absorber, 295 m from the source.
Solid lines Calculated using an analytical model for normal incidence (violet) and 5° incidence angle (orange).
Dashed line Calculated neglecting thermal transport. A full FEA study (data points) is being conducted by Fan Yang.

Figure 1 shows experimental results obtained at the Free-Electron Laser in Hamburg (FLASH), where a grating structure was exposed to a focused FEL beam. The edges facing the beam are about three times more sensitive to the X-rays than the smooth surface of a mirror in the same grazing-angle geometry. A model based on electrodynamic theory can explain the observed behaviour. Suitable materials to withstand single-shot damage at the European XFEL are light materials with high melting points, such as boron carbide or diamond-like carbon.

Suitable materials to withstand single-shot damage at the European XFEL are light materials with high melting points, such as boron carbide or diamond-like carbon.

To calculate the effect of heat load during an entire pulse train, thermal transport must be taken into account. Figure 2 shows calculations for a graphite beam absorber, which will be used, for example, in front of a photon shutter. The vertical axis shows the integrated radiation power leading to damage if the pulse train is 0.3 ms long. The solid lines were calculated using an analytical model for normal- and grazing-incidence

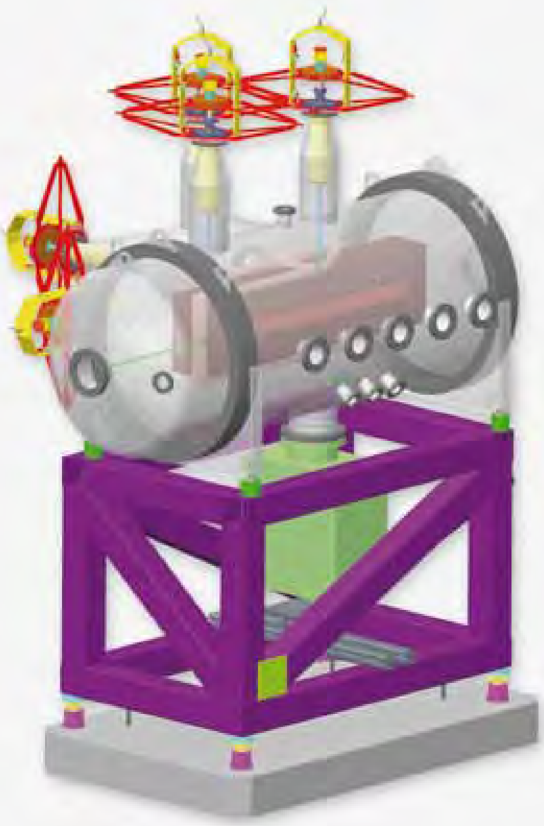

Figure 3 Design of the ultrahigh-vacuum chamber for offset and distribution mirrors (by Tino Noll from HZB and Antje Trapp from European XFEL)

geometry, where only the strongest thermal gradient in one dimension was taken into account. The thermal transport properties were approximated by constant values at temperatures of around 1000 K. The violet dashed line shows normal-incidence geometry without heat conduction, which is also the single-shot damage threshold for this case. Even though the beam diameter becomes smaller at higher photon energies, the increasing photoabsorption length leads to an increase of the single-shot damage threshold with photon energy. Below 3 keV, the absorption length becomes so small that thermal conduction into the bulk material can occur during a pulse train. Instead of the absorption length, thermal diffusion now becomes relevant for the pulse train damage threshold and the solid curve increases again for low photon energies. If the beam hits the graphite under a shallow angle of 5°, the damage tolerance is increased by a factor of about 5 and the influence of thermal conduction is also present at higher photon energies (orange curve). The full 3D finite element analysis (FEA) calculations, with temperature-dependent transport coefficients, lie a little below the corresponding curves of the analytical model. This is due to the reduced heat conduction at high temperatures and the varying heat capacity, which were neglected in the analytical model.

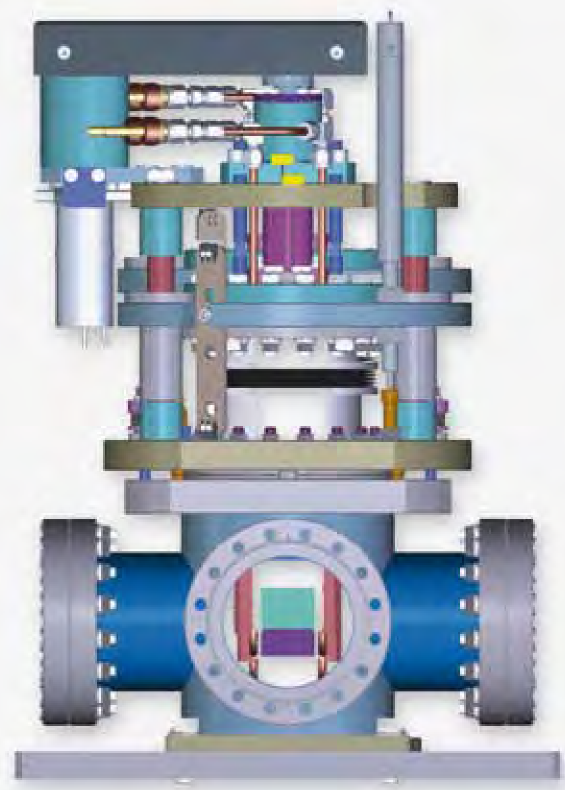

Figure 4 Synchrotron radiation aperture (design by Germano Galasso, European XFEL, and Alca Technology S.r.l. in Schio, Italy). The complete setup consists of two vertical blades and two horizontal blades, the latter of which are obtained by rotating the design by 90°.

A careful design and thermal analysis has to be done for of all components that can be exposed directly to the X-ray FEL beam. Furthermore, an equipment protection system is being developed to guard the X-ray optics against damaging beam conditions.

Design of a low-vibration UHV mirror chamber

Of particular importance for the pointing stability of the X-ray beam is a low vibration level of all reflective optics. In collaboration with the Helmholtz-Zentrum Berlin (HZB), the X-Ray Optics and Beam Transport group is developing a mirror chamber that fulfils the tight requirements for vibrations and ultrahigh vacuum (UHV). Five motorized axes arranged in a Cartesian parallel kinematics scheme will position the 800 mm long mirror substrates with a precision of 10 nm over a range of up to 80 mm. The mechanical precision and vibration level of the horizontal angle is expected to be about 20 nrad.

Figure 3 shows the design of the mirror chamber. The position of the mirror can be measured using absolute linear encoders outside the vacuum. In addition, a laser interferometer system is being developed that can measure positional and angular changes of the actual mirror with high precision through window flanges. To achieve the required precision, a temperature stability of the mirror chamber of better than 0.1 K must be achieved through local temperature control.

In front of the first mirror of each beamline, the powerful synchrotron radiation generated by the undulators around the X-ray FEL radiation must be reduced to minimize thermal deformations of the mirrors. This is achieved through apertures consisting of several-centimetre-thick, water-cooled boron carbide and tungsten blades that reduce the average power load on the mirror to a few watts (Figure 4). The apertures are designed in such a way that the blades do not touch, even when the apertures are fully closed. Thermocouples on each blade monitor the temperature during operation. The position of the blades is measured using absolute linear encoders outside the vacuum. Prototypes for mirror chambers and apertures will be tested in 2012.

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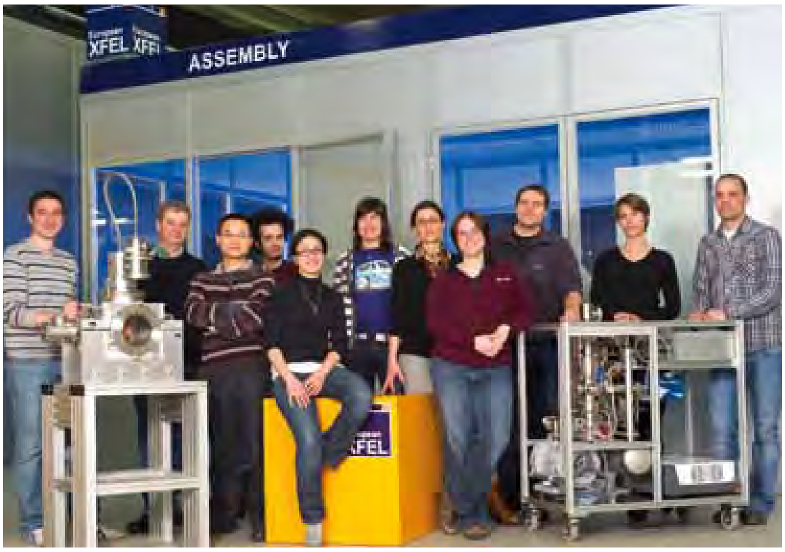

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X-RAY PHOTON DIAGNOSTICS

The X-Ray Photon Diagnostics group is responsible for designing, constructing, and eventually operating the diagnostics devices to measure and monitor the properties of photon pulses generated by the European XFEL. In 2011, the group leveraged collaborations with institutes around the world to fine-tune the design of the baseline diagnostics instrumentation for the new facility.

Purpose of diagnostics devices

At the European XFEL, diagnostics devices are required for two major tasks. First, they measure the pulse properties of the X-ray beam during commissioning and maintenance to enable and optimize lasing of the European XFEL. Second, they monitor each pulse of the photon beam during operation to provide users with the reference data they need to calibrate the experimental setup, as well as normalize and comprehend the experimental data.

The data delivered by the diagnostics devices will encompass beam properties such as pulse intensity, position, and spectral and temporal information. Shot-to-shot capability—the ability to measure the beam properties pulse by pulse—is challenging due to the 4.5 MHz repetition rate, but it is particularly important when the radiation is created using self-amplified stimulated emission (SASE), where each pulse is different because the radiation originates from shot noise.

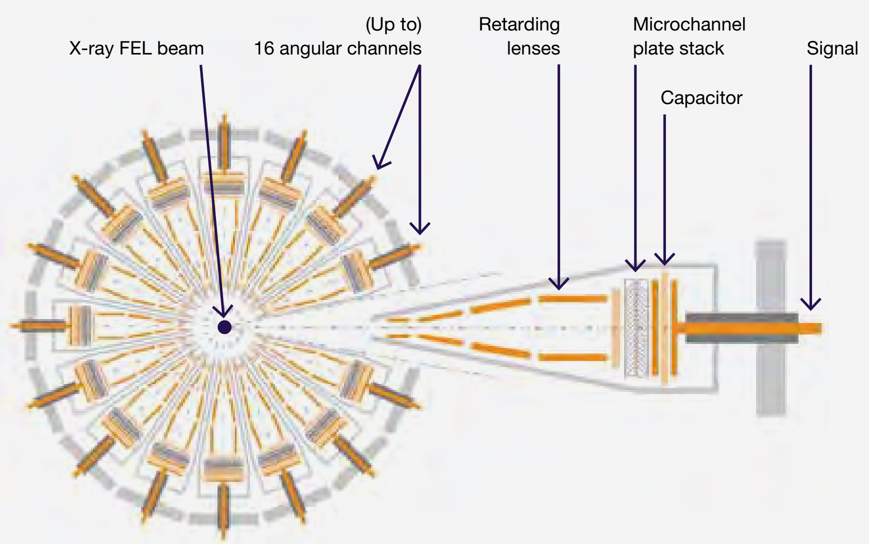

Figure 1 Schematic cross-sectional view of the photoemission spectrometer. One of the channels is enlarged to show more details. The view is in the plane transverse to the X-ray FEL beam.

Online photoemission spectrometer

A spectrometer is intended for online operation during user runs, when it will deliver shot-to-shot diagnostics information on the photon energy spectrum and, optionally, polarization. The development started in January 2011. The X-Ray Photon Diagnostics group established a successful collaboration with the P04 group of PETRA III at Deutsches Elektronen-Synchrotron (DESY), where such a spectrometer has been under development for several years and is now ready for operation as a diagnostics device (Figure 1). As a result, the X-Ray Photon Diagnostics group can rely on a mature layout as a basis for the required upgrades and modifications to satisfy the requirements of the European XFEL facility.

The development of a special simulation tool in 2011 allowed extended feasibility studies that strengthen confidence that the specifications can be achieved. The demanding goal of a photon energy resolution of 10^{-4} was demonstrated in simulations for the SASE3 undulator system, and appears to be within range even for higher photon energies, as can be concluded from comprehensive electron-optical simulations of the flight tube.

Significant advances were also achieved in the design of the data acquisition system. The general layout of the appropriate hardware and software was defined in 2011, confirming the shot-to-shot capabilities of the spectrometer. The low expected latency of only a few microseconds, coupled with advances in data reduction schemes, opens up the option of contributing to online control systems, such as the veto system, which rejects unwanted data, or the machine feedback system.

The promising results will be published in a conceptual design report (CDR) after review and approval in the first quarter of 2012.

Imaging stations

In May 2011, the X-Ray Photon Diagnostics group participated in an experiment on damage studies of various materials, carried out at the Free-Electron Laser in Hamburg (FLASH) using a focused beam of a few micrometres in diameter, at a wavelength of 4.6 nm, with varying pulse energy. This experimental campaign was an extensive collaboration between the SPring-8 Angstrom Compact Free-Electron Laser (SACLA) in Japan, the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in the USA, the Foundation for Fundamental Research on Matter (FOM) in the Netherlands, the Institute of Physics (IOP) at the Academy of Sciences of the Czech Republic, the IOP at the Polish Academy of Sciences, the Slovak Academy of Sciences (SAS), the Center for Free-Electron Laser Science (CFEL) in Germany, and

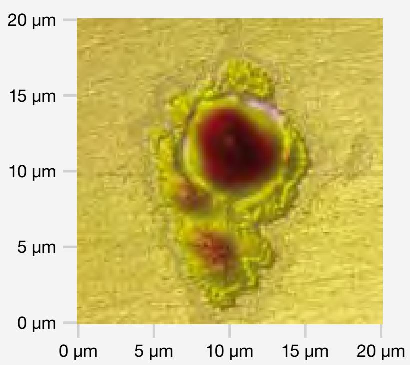

Figure 2 3D atomic force microscope (AFM) measurement of the damage inflicted by the FLASH FEL beam on the YAG sample (© V. Hajkova at IOP at the Academy of Sciences of the Czech Republic)

DESY, as well as the X-Ray Optics and Beam Transport group and the X-Ray Photon Diagnostics group at European XFEL.

Among the studied materials was cerium-doped yttrium aluminium garnet (YAG:Ce), which is a scintillator commonly used for beam profile imaging at synchrotron and free-electron laser (FEL) sources. Finding its single-shot damage threshold is important, as it is a scintillator candidate for beam profile imaging of the European XFEL beam at the imaging stations that will be strategically placed throughout the three SASE beamlines. Analysis is ongoing to assess the damage threshold of YAG:Ce in the aforementioned experimental conditions (Figure 2).

X-ray pulse arrival monitor

X-ray-pulse-induced ultrafast transient changes of the optical reflectivity in materials can be used as an effective tool for characterizing the cross-correlation of X-ray and optical laser pulses.

The X-Ray Photon Diagnostics group participated in a research campaign of William F. Schlotter at the Soft X-Ray Materials Science (SXR) end station of LCLS to explore the single-shot imaging method in the soft X-ray range up to 2 keV, in order to achieve an arrival time

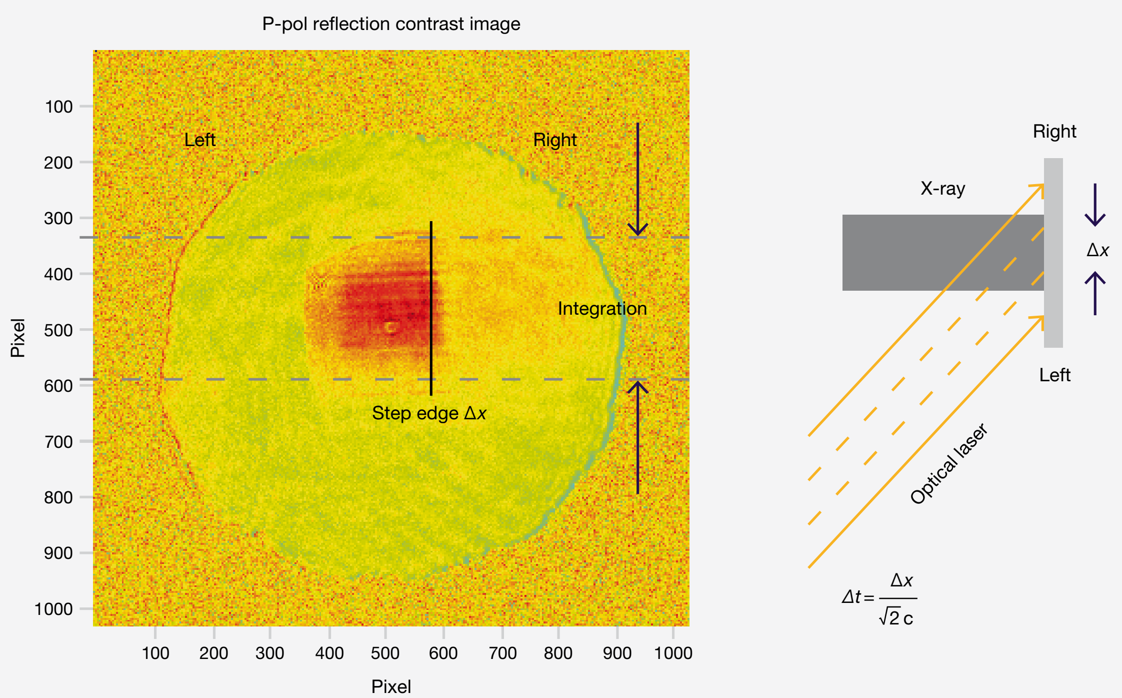

Figure 3 Single-shot contrast image The big circle indicates the optical laser. The red zone is the cross-correlation area.
Inserted graph Beam geometry and image orientation.

resolution below 50 fs. Polarization-resolved transmissive and reflective images were taken simultaneously to record the interaction of X-rays and optical laser pulses with Si_3N_4 thin-film samples. Figure 3 is a typical contrast image after X-ray irradiation. It is normalized using a background image without X-rays and allows the extraction of the X-ray arrival time information.

MCP-based detectors

In April 2011, a contract was signed with the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, for the production of detectors based on microchannel plates (MCPs), slabs of highly resistive material with a regular array of tiny tubes or slots used for the detection of particles and radiation. The institute will provide MCP-based detectors to be used during commissioning of the European XFEL for the SASE search and later characterization, such as gain curve measurements. Additionally, MCP imagers will allow us to acquire images of the photon beam.

In 2011, the conceptual design for the MCP-based detectors was completed. The construction of a prototype and its experimental evaluation at a synchrotron are planned for 2012.

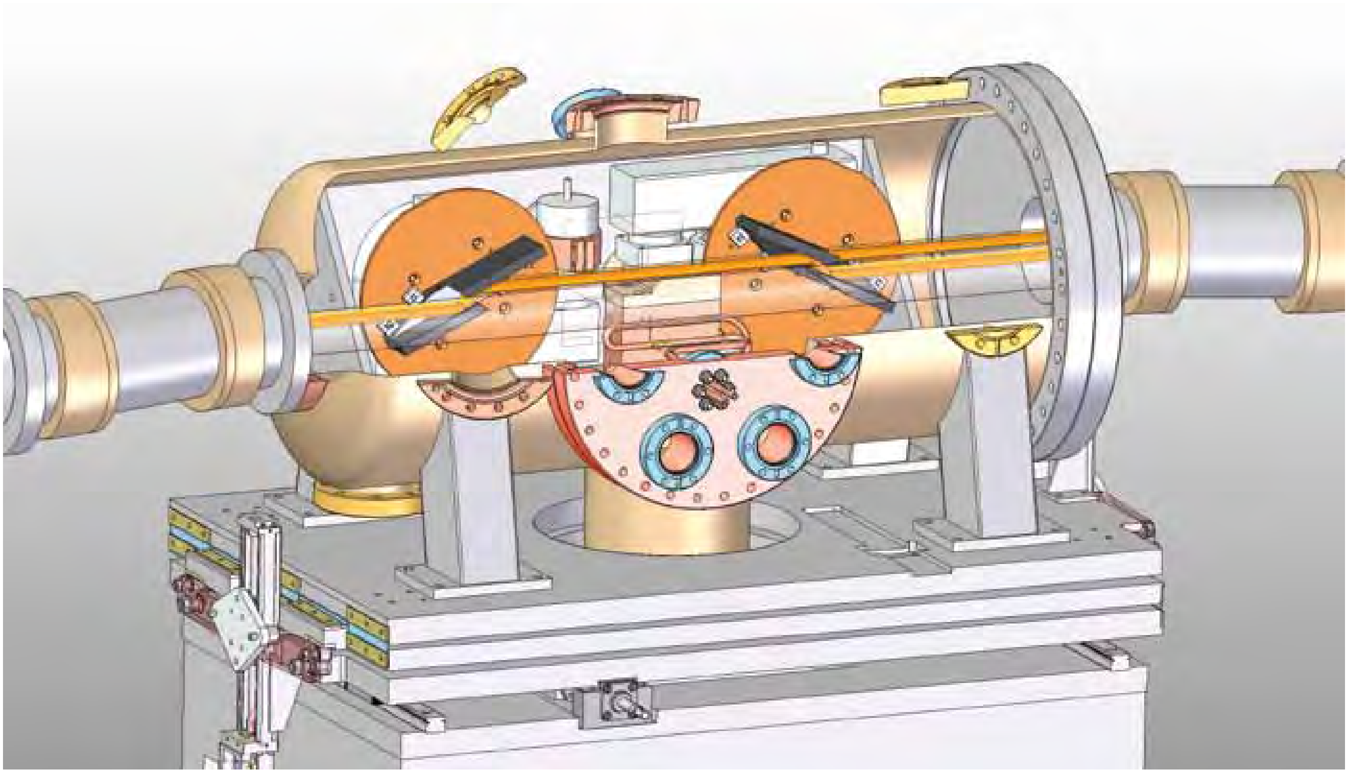

Figure 4 Rendered CAD picture of the commissioning spectrometer

Figure 5 CAD image of the UHV-compatible diamond detector housing and mounting plate

Undulator commissioning spectrometer

The review of the CDR for the undulator commissioning spectrometer was completed with last supplements to the CDR describing the day-one commissioning scenario. The preliminary design described in the CDR was the basis for further development. The prototype design has now reached a high level of detail (Figure 4). The main 3D models of the mechanical parts, including accessories like water cooling and adjustment stage, were designed. A first channel-cut crystal was manufactured in the crystal lab of the Hamburg Synchrotron Radiation Laboratory (HASYLAB), and will be tested in a prototype setup in early 2012. The major parts for the prototype—such as the goniometer, chamber, stages for adjustment, and mechanical parts—were ordered and, for the most part, delivered.

Collaborations with the Simulation of Photon Fields group of European XFEL and Helmholtz-Zentrum Berlin (HZB) have been established for undulator commissioning calculations and simulations. Different scenarios are being investigated.

The two main scenarios are:

- **Single-segment method**
  One active undulator segment, photodiode detection, and an energy scan that is achieved by tuning the monochromator angle, electron beam energy, or undulator gap.
- **Quadrupole kick method**
  Imaging the beam profile using two adjacent undulators. Results are detailed in the CDR documents.

Diamond detectors

In collaboration with Michal Pomorski at Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) in Saclay, France, two 50 µm and 300 µm thick diamond detector plates were designed in an R&D effort to monitor the position and intensity of the X-ray FEL beam on a pulse-resolved basis. The UHV-compatible detector setup was engineered at European XFEL (Figure 5).

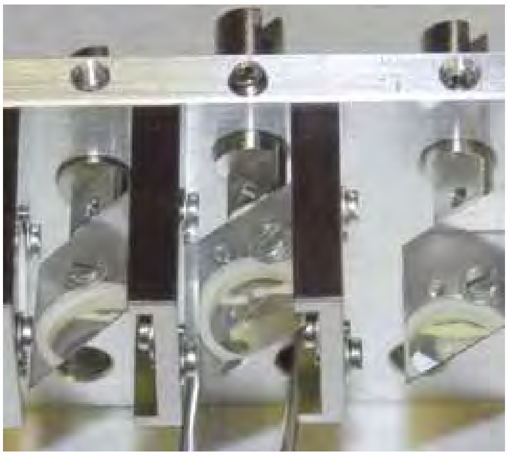

Figure 6 The wavefront imager setup that was engineered by the X-Ray Photon Diagnostics group

Wavefront imager

The X-Ray Photon Diagnostics group is involved in a collaboration project with the leading scientists of the Single Particles, Clusters, and Biomolecules (SPB) instrument at European XFEL (Adrian Mancuso) and the Coherent X-Ray Imaging (CXI) instrument at LCLS (Garth Williams) to study wavefront monitoring based on longitudinal intensity gradient imaging (Figure 6).

Experimental results from another collaboration, which implemented a wavefront sensing technique based on interferometric gratings, were published in 2011 [1].

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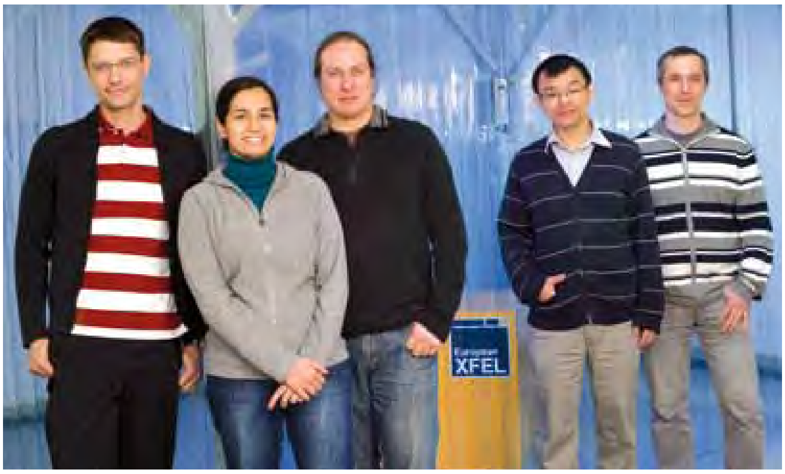

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05

SCIENTIFIC INSTRUMENTS AND EQUIPMENT

The European XFEL will open up exciting new research opportunities for scientists. In 2011, four of the six instruments for the startup version of the facility passed their conceptual design reviews. Progress was also made in the development of optical lasers and sample environment systems.

SCIENTIFIC INSTRUMENT FXE

The Femtosecond X-Ray Experiments (FXE) instrument will perform time-resolved pump-probe experiments on an ultrafast time scale. The FXE group presented the instrument design and is currently also using laboratory laser sources, synchrotron sources, and the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in California to test new strategies and acquire hands-on experience with X-ray free-electron laser (FEL) pump-probe measurements.

Conceptual design of the FXE instrument

The design of the FXE instrument strongly benefited from the proactive approach taken by the FXE group at synchrotrons and at LCLS in 2011. From the very beginning, the group decided to add more structural tools for the investigation of dynamic properties of matter. In 2011, the FXE group published the conceptual design of the FXE instrument and carried out several experimental campaigns in which the methodology proposed for implementation at the instrument was applied. The close collaboration with Martin M. Nielsen at the Technical University of Denmark (DTU) in Lyngby allowed the FXE group to discuss many details with experts from the adjacent company, JJ X-Ray, which strongly aided in the conceptual design.

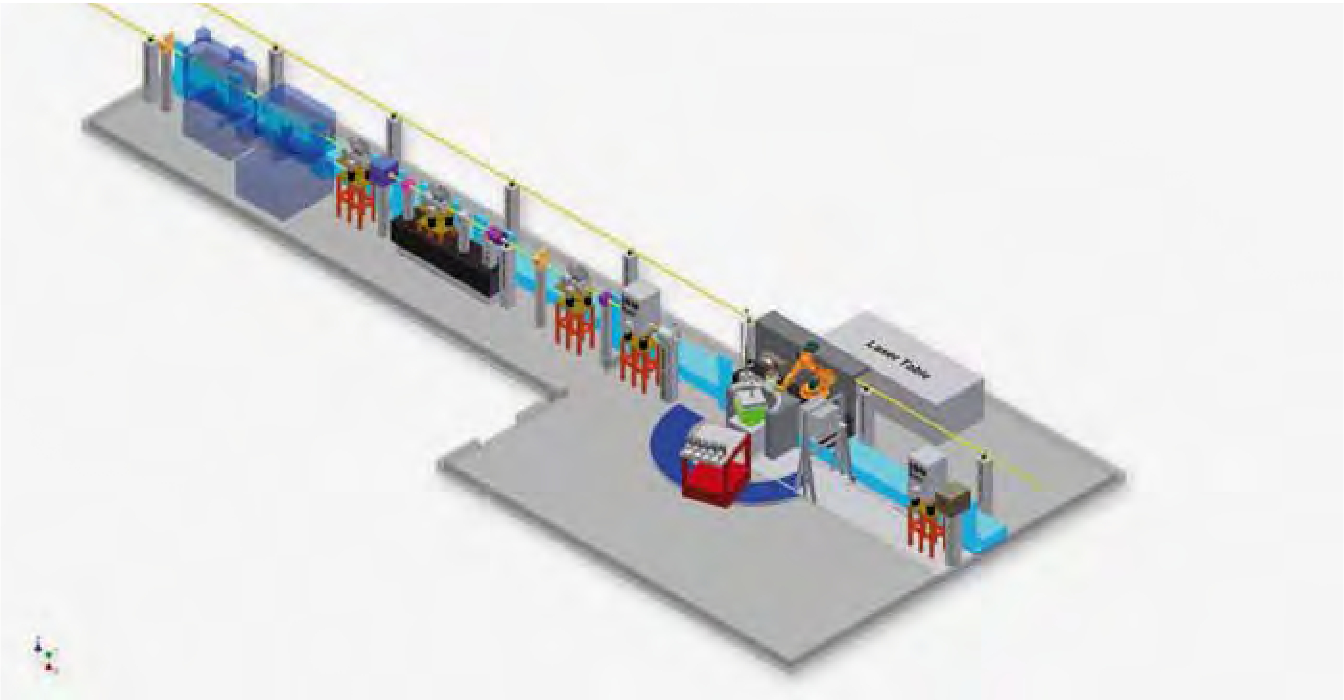

Figure 1 Conceptual design of the FXE instrument in the European XFEL experiment hall behind the SASE1 tunnel (© JJ X-Ray, Denmark)

The FXE instrument will enable ultrafast pump-probe studies of liquids and solids throughout the X-ray energy range of 5 to 20 keV, providing various devices for X-ray emission spectroscopy (XES), X-ray diffuse scattering (XDS), and X-ray absorption spectroscopy (XAS). The present schematic layout of the instrument, including all baseline components described in the FXE conceptual design report (CDR) [1], is shown in Figure 1.

For XES experiments, the FXE group will implement the following two types of spectrometers at startup:

- Dispersive (von Hamos-type) XES spectrometer with cylindrically shaped crystals and large solid-angle acceptance (> 1%)
- Five-element spherical (Johann-type) XES spectrometer with flexible Rowland circle radii to permit studies with moderate energy resolution of about 1 eV (for a bending radius of 1 m) and about 0.3 eV (for a bending radius of 2 m)

The FXE instrument will enable ultrafast pump-probe studies of liquids and solids throughout the X-ray energy range of 5 to 20 keV, providing various devices for X-ray spectroscopy and X-ray scattering.

The Johann-type spectrometer will be freely rotatable through nearly 180°, from nearly forward to backward scattering angles, around a vertical axis over the sample. The selection of both spectrometer geometries will permit the recording of single-shot XES spectra for rather concentrated samples (using the von Hamos dispersive spectrometer), while the five-crystal Johann spectrometer will allow the extraction of single-shot information at each selected XES energy. Thus, both spectrometers are capable of acquiring the femtosecond information with (single-)pulse-limited time resolution. In addition, the angular selectivity of the Johann spectrometer will enable the recording of femtosecond-resolved resonant inelastic X-ray scattering (RIXS) maps, which is complementary to the von Hamos spectrometer capabilities.

Experiments that exploit XDS techniques will benefit from the unique characteristics of the 2D large-area (1 Mpx) detector. The XDS experiments will record scattering patterns, in the forward direction, in the wide-angle range spanning up to a scattering-vector range (q-range) of 10 $Å^{-1}$, including some possible angular adjustments. The detector positioning will also permit measurements of the small-angle X-ray scattering patterns, as the distance between the sample and the detector can be increased to up to 3 m.

Furthermore, it is planned to include two dispersive-type single-shot XAS analysers (effectively acting as I_0 and I_1 detectors;

I_1: intensity of the light that interacted with the sample; I_0: reference beam) to permit single-shot acquisition of the X-ray spectra at burst mode repetition rates within the SASE1 bandwidth. An arrival time monitor will record the time delay between the exciting optical laser pulse and the FEL pulse shot by shot.

Most experiments can be performed in pink-beam mode (XAS, XES, and XDS), that is, using X-rays that have not passed a monochromator; but some experiments will require a reduced energy bandwidth of the incident beam, for which a bandwidth-limiting primary monochromator is foreseen. For RIXS studies, for example, a second monochromator with an even higher energy resolution will need to be included.

The baseline configuration will permit studies of liquids under ambient conditions, but space will be preserved for the inclusion of a specially designed vacuum chamber for samples requiring (ultra)high vacuum conditions, cryogenic conditions, or both. The beamline vacuum will be separated from the ambient sample environment by means of a diamond window, placed upstream from the sample, while keeping the sample environment (to the area detector and XES spectrometers) under helium atmosphere.

> In the nearly 1 km long beam transport system, beryllium lenses at a distance of 213 m from the source point will collimate the beam and limit its size at the tunnel exit to below 2 mm. Inside the FXE hutch, another set of lenses will focus the beam, so that the beam size on the sample can be varied in the 1–500 µm diameter range.

In the nearly 1 km long beam transport system, beryllium lenses (compound refractive lenses, or CRLs) at a distance of 213 m from the FEL source point will collimate the FEL beam and limit the beam size at the tunnel exit to below 2 mm. Inside the FXE hutch, another set of CRLs will focus the beam, so that the beam size on the sample can be varied in the 1–500 µm diameter range. Beam profile monitors beyond the focus will characterize the beam and its suitability for the experiment. Replacing the refocusing CRL assembly with a reflective Kirkpatrick-Baez (KB) mirror pair (about 0.5 m mirror length) is currently being scrutinized as part of developing the technical design report (TDR) scheduled for 2012.

Because femtosecond time resolution is paramount, the FXE instrument will make use of the shorter FEL pulses in low-charge mode, which in consequence reduces the potential heat load on the in-beam elements (arrival time monitor, spectrum analyser, and so on). Critical items in the beam are the upstream CRLs, the silicon monochromator, and the diamond window. These components reduce, in turn, the maximum number of FEL pulses within a burst to about 120 at 5 keV. This maximum number of pulses substantially increases for higher X-ray energies, so the full burst will be available for experiments at 12 keV or above.

In 2011, the FXE team led several experimental campaigns to exploit combined structural tools in laser–X-ray experiments at MHz repetition rates. This combination of structural tools has never before been implemented on time scales of nanoseconds and below.

The conceptual design was presented to and accepted by the newly founded advisory review team (ART) for the FXE instrument (see Chapter 7, "Organs and Committees"). Following the presentation to the European XFEL Scientific Advisory Committee (SAC) in April 2011, the FXE CDR was supplemented by improved concepts for the beam transport and delivery strategy, which will serve as the basis for the TDR in 2012.

Paving the science path

The FXE group is engaged in various national and international scientific projects, which deliver additional funding for FXE-related research activities. The EU-funded Cluster of Research Infrastructures for Synergies in Physics (CRISP) project (see Chapter 7, "Cooperation") will finance a postdoctoral scientist in 2012–2013 to construct a high-repetition-rate noncollinear optical parametric amplifier (NOPA) for optical laser systems. The SFB-925 (*Sonderforschungsbereich*) project, funded by Deutsche Forschungsgemeinschaft (DFG) and started on 1 July 2011, will explore correlated electron systems based on transition metal compounds, for which a Ph.D. student was hired in 2011. These studies will make use of the European XFEL laser lab located on the DESY campus, and exploit the 3 mJ / 3 kHz, 25 fs laser system installed there. A first prototype (N)OPA is expected to become operational in late 2012 to be used with the FXE MHz laser system.

Combining structural tools: MHz pump-probe experiments at synchrotrons

In 2011, the FXE team led several campaigns to exploit combined structural tools in laser–X-ray experiments at MHz repetition rates. These tools included XDS, XAS, and XES spectroscopies, each revealing a different property (electronic, nuclear, and spin) of the system under investigation. This combination of structural tools has never before been implemented on time scales of nanoseconds and below. Experiments were conducted at the Advanced Photon Source (APS) in Argonne, Illinois, Sector 7ID, and at the European Synchrotron

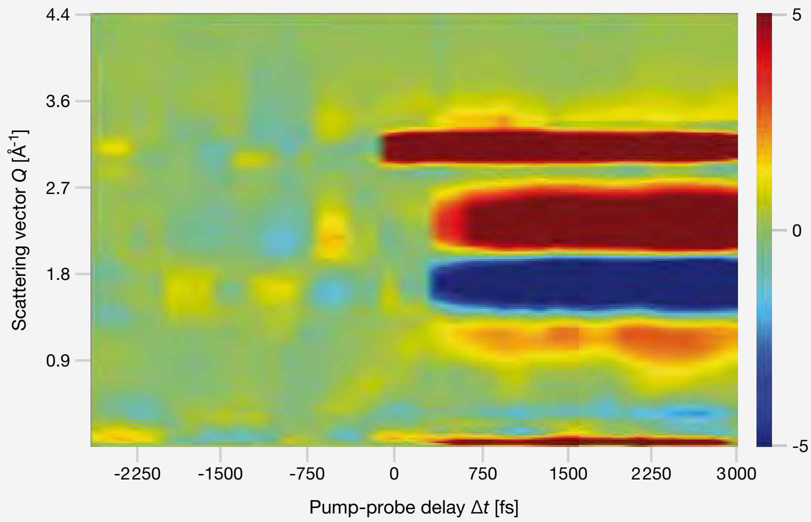

Figure 2 XDS of photo-excited $[Fe(bpy)_3]^{2+}$ scanning the pump-probe delay, showing different femtosecond modulations of the scattering pattern

Radiation Facility (ESRF) in Grenoble, Beamline ID26, each utilizing a fibre-based MHz laser system. At ID26, the FXE MHz laser system was synchronized to the ESRF storage ring.

These experiments were conducted in the collaborative framework of the international Ultrafast Dynamics Exploiting Complementary Structural Tools (UDECS) collaboration with participating parties from Denmark, France, Hungary, Sweden, and Switzerland. During these campaigns, different spin transition systems in solution were investigated, and the analysis of the simultaneously recorded data of both XES and XDS already provided a first glimpse of the molecular dynamics in solution with atomic-scale resolution, thus bringing the dream of recording a “molecular movie” closer to reality. Also, the use of MHz repetition rates for these types of experiments permitted the use of more than 10^{12} photons per data point, which is several orders of magnitude higher than in previous time-resolved X-ray spectroscopic studies at synchrotrons.

Testing the FXE conceptual design at LCLS

In August 2011, the FXE group led an experiment at the X-Ray Pump-Probe (XPP) scientific instrument at LCLS (Figure 2). This four-day beamtime was divided into one day of preparation and setup, and three days of data collection on three different samples: $Fe(bpy)_3$ (bpy = bipyridine), $Fe(terpy)_2$ (terpy = terpyridine), and a bpy-based bimetallic donor–acceptor compound with a ruthenium (Ru) (donor) and a cobalt (Co) (acceptor) central atom (RuCo compound). All compounds were investigated to study the ultrafast charge transfer and subsequent structural and spin state changes occurring on the femtosecond time scale. Hereby the timing jitter between different laser and FEL pulses was the limiting factor in time resolution, nevertheless permitting the dynamics to be resolved down to 250 fs time resolution.

In a second campaign at the Soft X-Ray Materials Science (SXR) instrument at LCLS, we attempted to improve the time resolution by recording single-shot soft X-ray spectra on thin (1 μm thick) solid $Fe(bpy)_3$. The angled overlap between laser and FEL pulses allowed us to project the femtosecond time axis onto a spatial coordinate of the area detector recording the transmitted FEL intensity. The first half of experiments were dedicated to recording the time response with very low (that is, non-damaging) FEL intensities to establish a similar time response as obtained at the XPP instrument the month before. Then several (up to 100) individual samples were recorded in single-shot mode with the full FEL intensity. The analysis is still under way, with the goal of eventually recording the ultrafast initial events with pulse-limited time resolution (around 50–70 fs) and unravelling the initial events during a light-triggered reaction of a spin transition system. ■

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Group members
Christian Bressler (group leader), Wojciech Gawelda, Andreas Galler, and Enrique Cuña (not shown)

SCIENTIFIC INSTRUMENT MID

The Materials Imaging and Dynamics (MID) instrument aims to investigate nanostructured materials and dynamics on the nanoscale. Areas of application are material sciences, nanomaterials, and the dynamics of condensed matter.

Experiments at the MID instrument

Experiments at the MID instrument will utilize the scattering of coherent X-rays and detection of the coherent diffraction pattern. In coherent X-ray diffraction imaging (CXDI) experiments, 2D and 3D structures of condensed-matter samples will be investigated with resolutions reaching into the 10 nm regime. Possible sample systems are nanocrystals, nanostructures on or buried under surfaces, and crystallites of a compound sample. Using X-ray photon correlation spectroscopy (XPCS), the equilibrium and non-equilibrium dynamics of condensed matter can also be studied. These experiments, which are often carried out with disordered solids or liquids, or using soft matter, investigate the temporal fluctuation of structural parameters (for example, the distance of nearest neighbours).

Launching the MID group

The MID group initiated its activities in 2011, when leading scientist and group leader Anders Madsen joined European XFEL. The main objectives for 2011 were to found the group and prepare the conceptual design report (CDR) for the MID instrument [1], which will be located at the SASE2 undulator beamline in the experiment hall in Schenefeld.

Conceptual design report

The MID CDR was written, peer reviewed, and published in 2011. Its first part reiterates the science case for the use of hard X-ray free-electron laser (FEL) beams in materials science, with particular focus on experiments utilizing the coherence properties and the time structure of the beam. Certain classes of experiments can be seen as natural extensions of work that has been successfully conducted at synchrotron radiation sources (for example, CXDI and XPCS). With the flux, coherence, and time structure of the European XFEL beam, however, it is anticipated that entirely new applications and techniques will emerge that will enable exciting new science.

This new window of opportunity is described in the second part of the CDR. Based on estimates for flux, coherence, scattering cross sections, signal-to-noise ratios, and so on, this part of the CDR discusses in detail which experiments are likely to be possible and how they must be conducted. This discussion serves as a reality check of the science case. In the coming years, much effort will be devoted to experimental tests of the methods and constraints presented here.

The final part of the CDR outlines the beamline components, the instruments, and the detectors needed to reach the scientific goals. Obviously, these very ambitious goals require major R&D efforts in several areas, including X-ray optics, X-ray detectors, and beam diagnostics. The data acquisition chain, beamline control system, and computing infrastructure are also essential for the successful operation of the MID station, which is expected to receive first photons in the second half of 2015.

Certain classes of experiments at the MID instrument can be seen as natural extensions of work that has been successfully conducted at synchrotron radiation sources. With the flux, coherence, and time structure of the European XFEL beam, it is anticipated that entirely new applications and techniques will emerge and enable exciting new science.

An advisory review team (ART) has been established for every instrument of the European XFEL facility. The review of the CDR took place on 27 September with participation of the ART and members of the European XFEL Management Board (see Chapter 7, “Organs and Committees”). The approved CDR was then published in a revised version on the European XFEL website.

Technical design report

The next step towards a final design is a workshop to be held in late 2012 or early 2013, with the aim of discussing recent results and experiences from the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory and elsewhere, and their possible influences on the MID science case and design. The work on the technical design report (TDR) for the MID instrument will be initiated in 2012. Depending on the engineering resources available, the TDR could be ready as early as 2013.

Research activities

On 1 September 2011, Jörg Hallmann from Georg-August-Universität Göttingen joined the group as research scientist. A number of scientists are required to maintain an active experimental programme that must be pursued to gain experience with hard X-ray self-amplified spontaneous emission (SASE) beams and further develop the MID case.

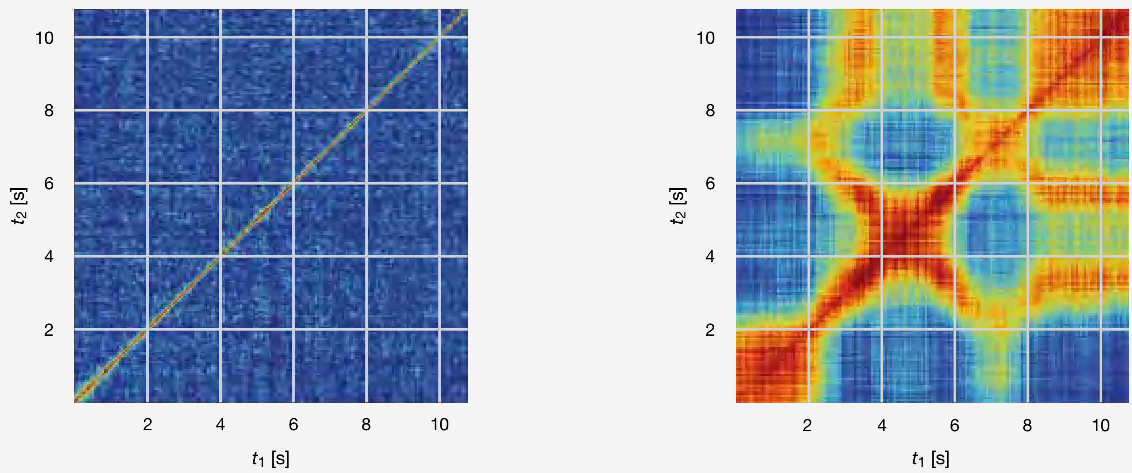

Figure 1 Two-time correlation functions nicely illustrate the difference between equilibrium dynamics (left) and more complicated non-equilibrium dynamical behaviour (right). XPCS data taken on a colloidal suspension near the glass transition. Data courtesy of P. Kwasniewski, A. Fluerasu, A. Madsen et al. from a collaboration between ESRF, BNL, and European XFEL. Data from beamline ID10A (ESRF).

Additional research and engineering positions in the MID group are expected to be filled in 2012.

In summer and autumn 2011, the MID group was involved in two commissioning runs at LCLS with the objective of testing hard X-ray beamline optics. The MID group aims to strengthen its involvement in coherent hard X-ray experiments at SLAC in 2012. To this end, the experience gained during the runs at the X-Ray Pump-Probe (XPP) and X-Ray Correlation Spectroscopy (XCS) instruments at LCLS has been particularly important.

During winter and spring 2012, the MID group will have two user beamtimes at LCLS with the aim of measuring structural dynamics at atomic and molecular length scales in disordered materials, such as glasses, liquids, and gels. The granted beamtimes result from fruitful collaborations with the European Synchrotron Radiation Facility (ESRF) in Grenoble, LCLS, Universitat Politècnica de Catalunya (UPC) in Barcelona, and Université Claude Bernard Lyon 1, as well as with DESY, ESRF, Johns Hopkins University in Maryland, LCLS, and the University of Ottawa, respectively.

In autumn 2011, the MID group participated in two XPCS beamtimes at ESRF in collaboration with scientists from Brookhaven National Laboratory (BNL), ESRF, Università degli Studi di Parma (UNIPR), and Université Joseph Fourier (UJF) in Grenoble. At the heart of the experiments were advanced speckle correlation techniques and the usage of the latest generation of 2D pixelated complementary metal oxide semiconductor (CMOS) detectors to record the scattering data.

Figure 1 shows so-called “two-time correlation functions” (TTCF) of the intensity scattered from concentrated suspensions of poly(methyl methacrylate), or PMMA, colloids in decalin. Such TTCFs allow a distinction to be made between equilibrium and non-equilibrium dynamics. A variance analysis of the TTCF will reveal whether the dynamics is of Gaussian nature or governed by heterogeneity (for example, displaying an intermittent avalanche-type behaviour).

The hydrodynamics of concentrated colloidal suspensions continues to fascinate researchers with new discoveries at the intersection of physical chemistry, glass physics, and many-body physics. In addition, colloidal systems with diameters in the nanometre range may also be seen as toy models for studying dynamics in atomic systems, where experiments with the necessary spatial and temporal resolution are much more challenging. Investigations of dynamics (slow to ultrafast) at atomic and molecular length scales are at the heart of the MID science case. Hence, there is a natural connection between the physics the MID group studies today at synchrotron sources and the future experimental programme at the MID instrument. ■

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doi:10.3204/XFEL.EU/TR-2011-008

Group members
Anders Madsen (group leader) and Jörg Hallmann

SCIENTIFIC INSTRUMENT SPB

The Single Particles, Clusters, and Biomolecules (SPB) instrument is a hard X-ray instrument for imaging single nanoscale samples, such as nanocrystals or possibly even single molecules. It aims to enable users to create 3D images of individual biological macromolecules, in particular those that cannot be observed by conventional methods.

Conceptual design report

For the SPB group, the most significant event in 2011 was the publication of the conceptual design report (CDR) [1], a major milestone in the realization of the instrument. The conceptual design takes into account user needs, which were first presented in 2008 at the SPB Instrument Workshop in Uppsala and have been refined with knowledge that has come to light since then.

The conceptual design of the SPB instrument was presented and reviewed by the SPB advisory review team (ART), which consists of seven experts in disciplines as diverse as structural biology, coherent imaging, sample injection technology, and free-electron laser (FEL) and synchrotron instrumentation (see Chapter 7, “Organs and Committees”). The ART offered valuable advice, suggestions, and support by openly sharing experience and expertise. The resulting report is now available online at the European XFEL website.

The publication of the conceptual design report was a major milestone in the realization of the SPB instrument.

Team buildup and more collaborations in 2011

In 2011, the SPB group underwent significant growth, tripling in size from a team of one in 2010. Andrew Aquila and Klaus Giewekemeyer joined the group as scientific staff in October and November 2011, respectively. They are now contributing substantially to the research, design, and realization of the SPB instrument. Giewekemeyer recently completed his Ph.D. at Georg-August-Universität Göttingen on novel approaches to coherent X-ray microscopy applied to biological specimens. Aquila joined the team from the Center for Free-Electron Laser Science (CFEL) and the Hamburg Synchrotron Radiation Laboratory (HASYLAB) at Deutsches Elektronen-Synchrotron (DESY), where he recently worked on time-resolved FEL nanocrystallography. Giewekemeyer and Aquila’s knowledge will support the goal of delivering a single-particle imaging instrument that exploits both coherent diffractive imaging and nanocrystallography for structure determination of biological specimens.

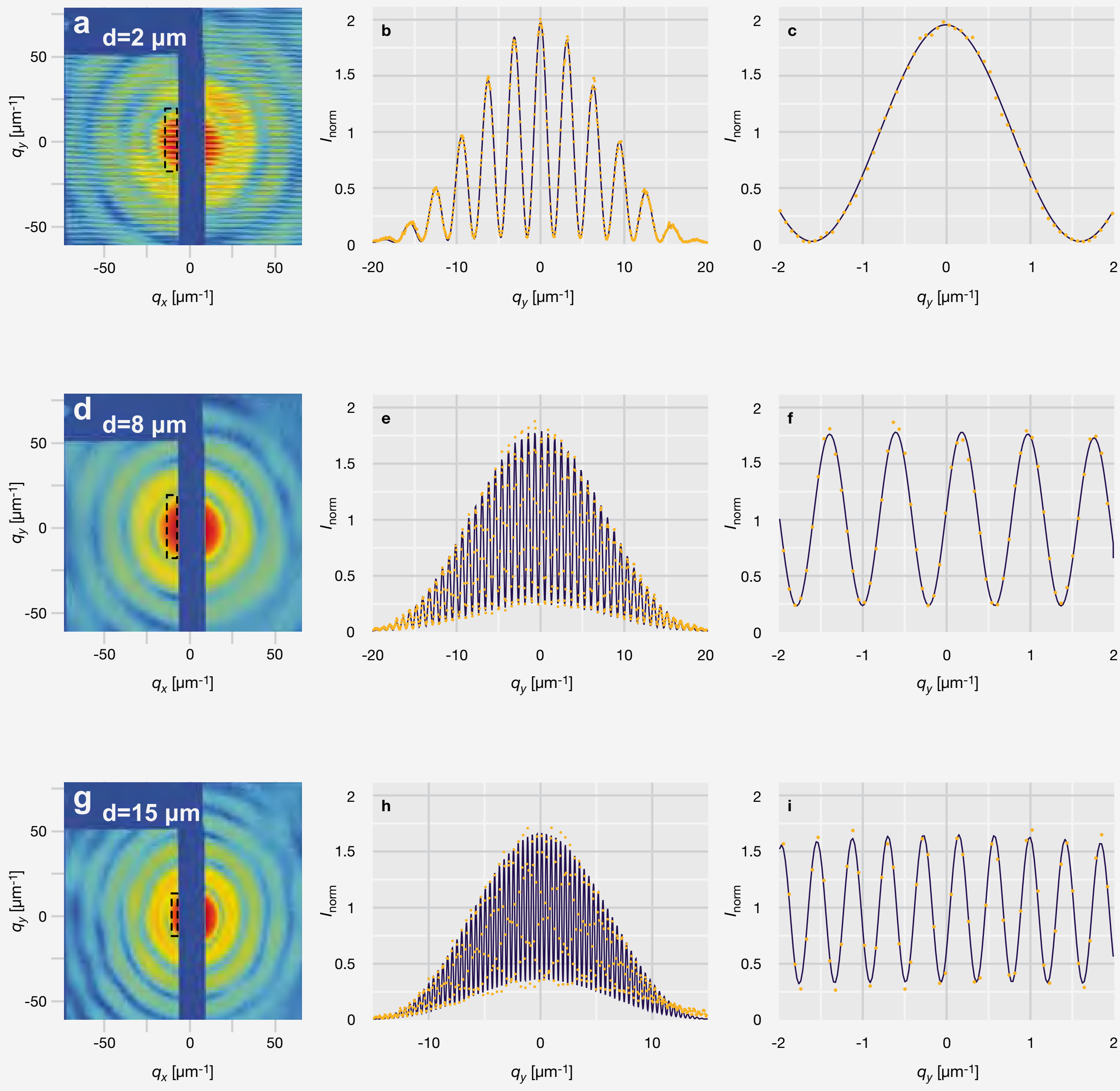

Figure 1 Measured two-pinhole diffraction patterns. The excellent visibility of the fringes in the patterns already indicates a high degree of coherence.
Left column Interference fringes from pinholes separated by 2 (a), 8 (d), and 15 µm (g), each from a single shot of the LCLS beam.
The area used for the analysis of the transverse coherence is shown by the dashed black rectangle close to the centre of the patterns.
Middle column Line scans of the interference fringes on the right edge of the marked region, experimental data (orange dots), and results of the theoretical fit (violet lines).
Right column Enlarged regions of the line scans shown in the middle column, clearly showing the high quality of the fit and the excellent fringe visibility.
Figure originally published in [2].

In December 2011, Duane Loh of SLAC National Accelerator Laboratory in California was a guest of the SPB group for a week. Loh is an expert in the theory and computation required to interpret the randomly oriented diffraction patterns collected in single-particle imaging experiments. Together with Burkhard Heisen of the European XFEL DAQ and Control Systems group, Loh and Giewekemeyer have started collaborating on the application of these orientation algorithms.

A collaboration including the SPB group leader Adrian Mancuso used Young's double pinhole measurements to determine that the LCLS beam was indeed highly coherent. Groups working on single-particle imaging with X-ray FELs can now rely on a proven technique to measure coherence and on the knowledge that an actual X-ray FEL beam has been observed to be highly coherent.

While working towards the commissioning of the European XFEL, the SPB group continues to perform imaging and beam characterization experiments at existing FEL and synchrotron facilities. As an example, in 2011, the SPB group (and many others) published successful measurements of the coherence of an X-ray FEL beam carried out at the Linac Coherent Light Source (LCLS) at SLAC [2]. Spatial coherence, in particular, is necessary to fully exploit the FEL beam to image non-crystalline samples. A collaboration led by DESY with partners from across three continents—including the SPB group leader Adrian Mancuso, who was based at DESY prior to his affiliation with European XFEL—used Young's double pinhole measurements to determine that the LCLS beam was indeed highly coherent (see Figure 1). This result is important for all groups working on single-particle imaging, or "coherent imaging", with X-ray FELs, as they can now rely on a proven technique to measure coherence and on the knowledge that an actual X-ray FEL beam has been observed to be highly coherent.

Figure 2 New group member Andrew Aquila in the lab at LCLS

Outlook for 2012

To further collaboration with the CFEL Theory Division, the SPB group plans to host Harry Quiney, head of the Theory and Modeling Program at the ARC Centre of Excellence for Coherent X-ray Science at the University of Melbourne, Australia. Quiney will visit Hamburg over a two-week period to exchange ideas with European XFEL and CFEL scientists about how to best describe the interaction of an FEL pulse with biomolecules, as well as to discuss the methods of interpreting diffraction data measured from such particles.

The year 2012 will require a significant investment of effort toward the technical design of the SPB instrument. The technical design report is scheduled for delivery in spring 2013. The SPB group has already begun to evaluate the precise geometry of the optics and mechanics. The group will also continue experiments at light sources around the globe, including imaging experiments at the Advanced Photon Source (APS) at Argonne National Laboratory in Illinois, as well as participating in a number of experiments at LCLS in California.

With more staff due to start in 2012, and an ambitious technical design target for 2013, the SPB group is confident that it will meet its objectives in the years ahead.

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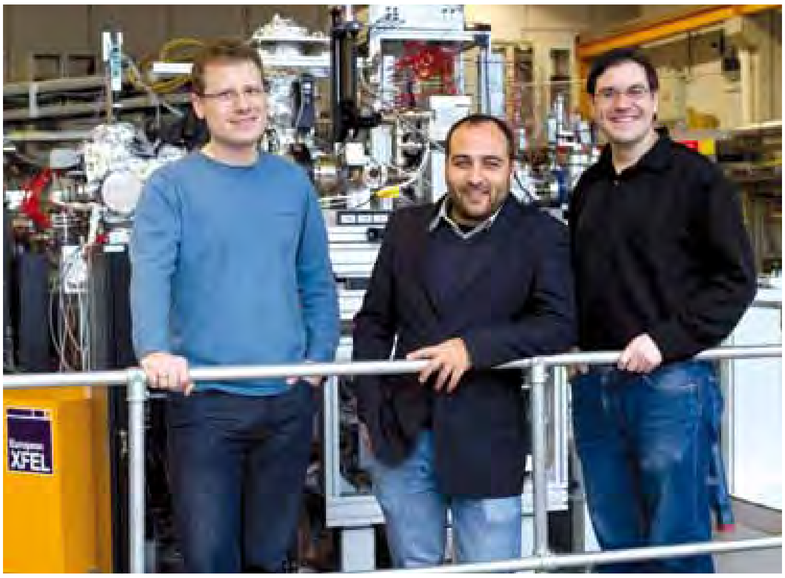

Group members
Klaus Giewekemeyer, Adrian Mancuso (group leader), and Andrew Aquila

SCIENTIFIC INSTRUMENT SQS

The Small Quantum Systems (SQS) instrument will be dedicated to the study of atomic, molecular, and cluster systems in the soft X-ray wavelength regime. These relatively simple objects are ideal samples for scientists to identify and study the fundamental interaction of matter with the ultrashort and highly intense X-ray pulses of the European XFEL. Areas of application are atomic and molecular physics, astrophysics, plasma diagnostics, chemical dynamics, as well as bioscience and nanoscience.

Conceptual design report

In 2011, the most significant event for the SQS group was the completion of the conceptual design report (CDR) [1]. The CDR, which is posted on the European XFEL website, is one of the important milestones for the realization of the instrument.

In April 2011, the European XFEL Scientific Advisory Committee (SAC) approved the CDR for the SQS instrument. The report outlines the general layout and the experimental concepts of the instrument, which mainly includes the focusing optics, the ultrahigh-vacuum experiment chamber, and the diagnostics tools needed close to the experiment.

The optics will consist of a pair of Kirkpatrick-Baez (KB) mirrors with an appropriate bending system, which will enable focus diameters as small as 1 μm and the possibility to vary the position of the focus point along the beam propagation axis. This will allow the installation of two experiment chambers with almost equal focus parameters.

The SQS instrument will consist of two vacuum chambers: the atomic-like quantum systems chamber dedicated to studies of atoms and small molecules, and the nanosize quantum systems chamber dedicated to larger samples and imaging techniques.

The choice of two experiment chambers was necessary to host the numerous electron, ion, and photon analysers that are required for the different types of experiments envisaged at the SQS instrument, especially for the various coincidence experiments made possible by the uniquely high repetition rate available at the European XFEL. In addition, the two spatially separated vacuum chambers facilitate the use of a large variety of gas phase targets, in particular molecular jets, cluster and nanoparticle beams, and large biomolecules. The SQS instrument will therefore consist of two vacuum chambers: the atomic-like quantum systems (AQS) chamber dedicated to studies of atoms and small molecules, and the nanosize quantum systems (NQS) chamber dedicated to larger samples and imaging techniques

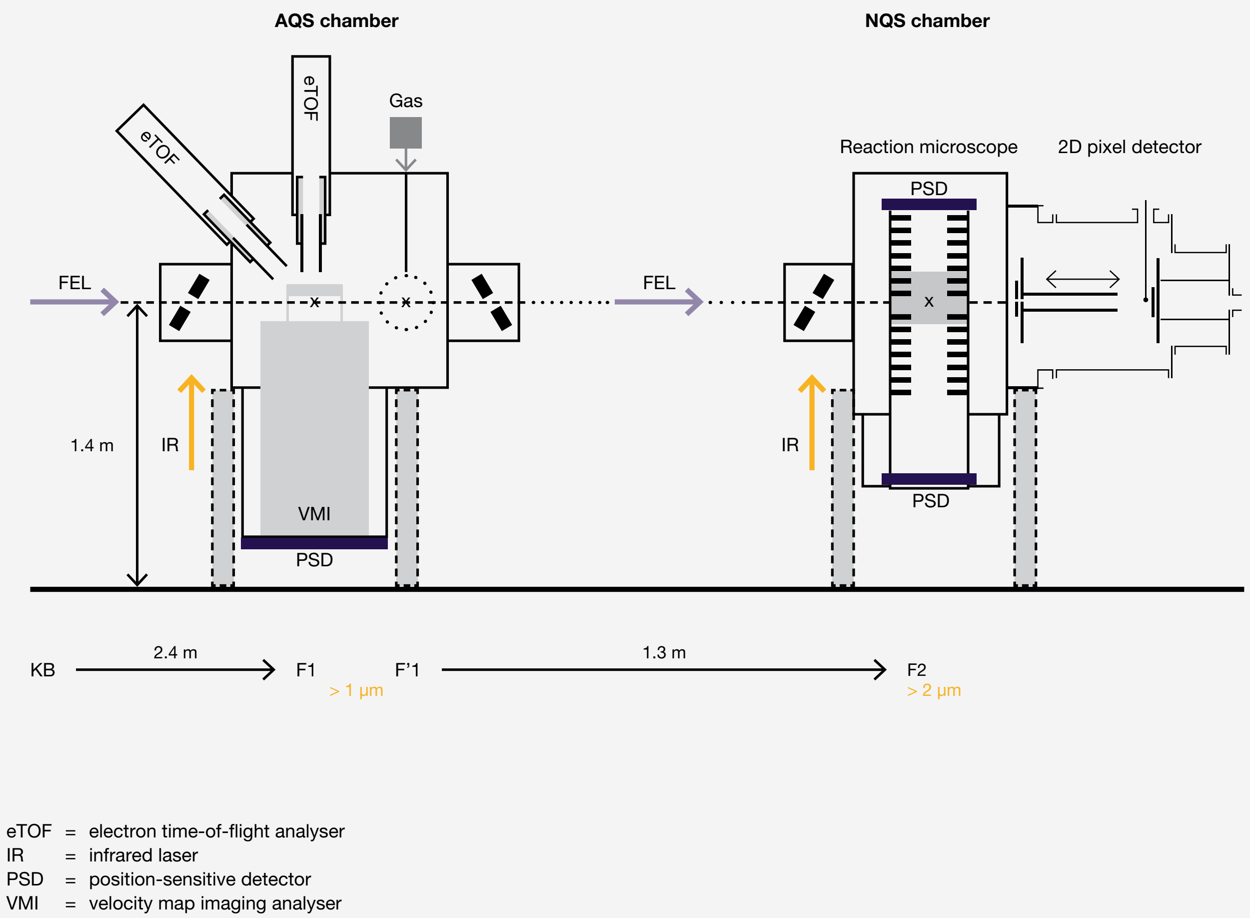

Figure 1 Schematic layout for the two experiment sections of the SQS instrument.
Left Section devoted to experiments on AQS.
Right Section devoted to NQS.

(Figure 1). The principal analysers and their envisaged performances are summarized in the CDR.

The CDR also provides a compilation of the photon beam diagnostics that are required for the experiments, as well as information about the additional optical laser system, possible add-on equipment, and the data acquisition modes capable of using the high repetition rate of the European XFEL. The CDR was presented during a one-day workshop to the external advisory and review team (ART), which is composed of seven scientists representing the different scientific communities interested in the SQS instrument (see Chapter 7, “Organs and Committees”). The ART approved the general concepts outlined in the CDR and offered suggestions for the technical design report.

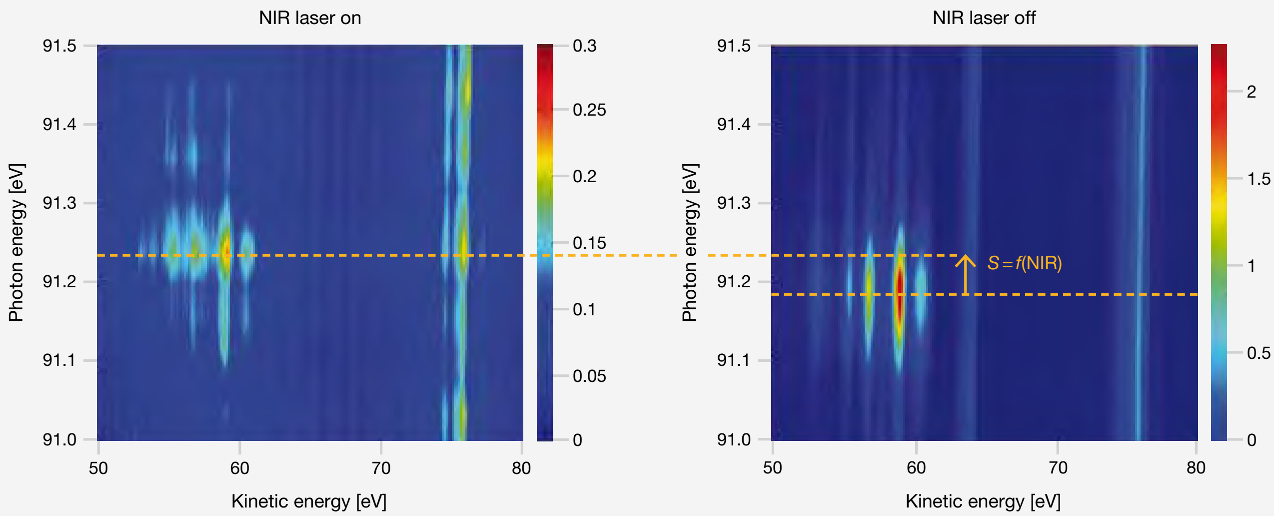

Figure 2 Electron spectra of atomic Kr upon excitation in the region of the Kr* $3d^9 4s^2 4p^6 5p$ resonance at 91.2 eV recorded with (left) and without (right) the presence of the near-infrared (NIR, 800 nm) laser in the interaction region. The Kr^+ $3d^{10} 4s^2 4p^4 5p$ ionic states are seen in the region of kinetic energies smaller than 61 eV.

Experiments at FLASH and LCLS

In 2011, the SQS group continued exploring the new science areas that are opened up by the new extreme-ultraviolet (XUV) and X-ray free-electron laser (FEL) sources, in particular by conducting experimental campaigns at the Free-Electron Laser in Hamburg (FLASH) at Deutsches Elektronen-Synchrotron (DESY) and the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in California. In addition, more specific investigations and tests of particular experiment devices were performed using the laser laboratory in the PETRA III experiment hall at DESY.

The campaigns concentrated on two-colour experiments using an intense optical laser synchronized to the XUV FEL radiation. This type of two-colour pump-probe study will be one of the major applications for the SQS instrument, taking advantage, in particular, of the short pulse duration of the European XFEL. In a series of experiments at FLASH, the group studied, for example, the influence of a strong optical field on the relaxation dynamics of a resonant excitation in atomic krypton (Kr). Excitation of the Kr* $3d^9 4s^2 4p^6 5p$ resonance with FEL pulses of 91.2 eV photon energy is followed by electronic relaxation to Kr^+ $3d^{10} 4s^2 4p^4 5p$ ionic states through resonant Auger decay (Figure 2).

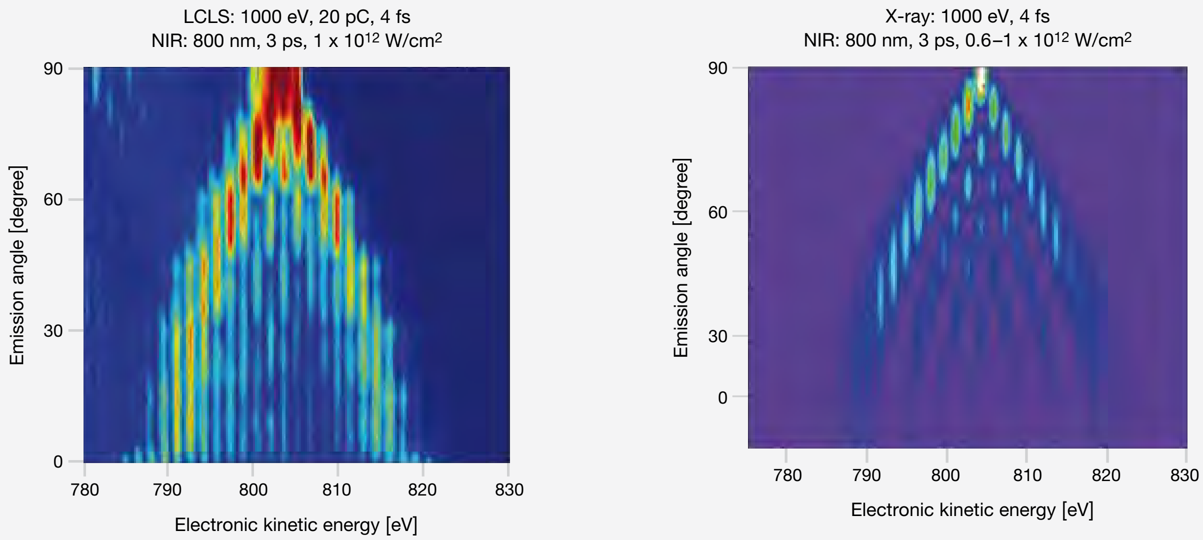

Figure 3 2D angle-resolved spectra of KLL Auger electrons from Ne in the laser field presented as a colour-scaled plot.
Left: Experimental spectra.
Right: Calculated spectra.

The experimental campaigns concentrated on two-colour experiments using an intense optical laser synchronized to the XUV FEL radiation. This type of two-colour pump-probe study will be one of the major applications for the SQS instrument.

The presence of an additional near-infrared (NIR, 800 nm) laser with pulse energies of up to 3 x 10^{12} W/cm^2 in the interaction region has two clear consequences. First, due to the ponderomotive shift that is induced by the strong NIR field, the resonance is excited at higher photon energies. That is, the atomic Kr target becomes more and more transparent at the nominal energy of the resonance as a function of the laser intensity. Second, the NIR laser can also lead to the ionization of the excited 5p electron before the resonant Auger decay takes place. This process results in the formation of a 3d core hole state, which relaxes through normal Auger decay to a doubly charged final ionic state; that is, the NIR laser can modify the electronic relaxation dynamics as a function of laser intensity by controlling the production of singly and doubly ionized states, respectively. The experimental results are in agreement with the theoretical treatment of the underlying processes performed by the group of Peter Lambropoulos at the Foundation for Research and Technology – Hellas (FORTH) in Crete.

In another series of experiments, we studied the laser-assisted Auger decay (LAAD) of atomic neon (Ne) using angle-resolved electron spectroscopy [2]. These results obtained at the Atomic, Molecular, and Optical Science (AMO) end station of LCLS underline the importance of very short XUV pulse durations (a few femtoseconds). The close similarity of the different time scales relevant for the considered process—that is, XUV pulse duration (< 5 fs), lifetime of the Ne KLL Auger decay (2.4 fs), and duration of one optical cycle of the 800 nm optical laser (2.6 fs)—results in pronounced oscillations in the intensity distribution of the angle-resolved sideband structures (Figure 3). These oscillations are interpreted as interferences arising from electron emission within one optical cycle of the NIR field. The interferences, which are studied here for an atomic system, will show up in all angle-resolved two-colour experiments independent of the target (that is, atoms, molecules, clusters, or solids). ■

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Group members
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OPTICAL LASERS

The Laser group will provide laser equipment for pump-probe and other experiments at the European XFEL. This equipment will be developed in-house and in close collaboration with industrial and academic partners.

Launching the Laser group

In late 2010, a leading laser scientist was appointed to build a team of highly motivated laser specialists to reach the ambitious laser technology goals for the European XFEL in time for the start of operations in 2015. By mid-2011, two permanent members had joined the group. In addition, through the framework of cooperation between the European XFEL and the Spanish Center for Ultrashort Ultraintense Pulsed Lasers (CLPU) in Salamanca, a laser expert from CLPU joined the Laser group for a period of five months. Recruitment continues as a larger team will be needed to achieve the goals according to the schedule.

Identifying requirements

One of the most urgent immediate tasks the new group faced was to analyse laser requirements from various vantage points, consolidate all information, and draft a project and budget plan. Input was gathered from leading instrument scientists and potential users to set goals for laser specifications. In addition, types and numbers of laser installations in the experiment hall were defined, with special consideration given to beam delivery requirements and space constraints.

One of the most urgent immediate tasks the group faced was to analyse laser requirements from various vantage points, consolidate all information, and draft a project and budget plan.

According to the project and budget plan approved by the European XFEL Management Board, the experiment hall will be equipped with a number of different lasers. The experiment areas of SASE1, SASE2, and SASE3 will each have a laser hutch containing a synchronized pump-probe laser, placed for the shortest possible beam delivery to the various instruments.

The pump-probe laser goals are summarized as follows:

- 10 Hz burst mode operation, matching the intra-burst bunch pattern of the linear accelerator with up to 2 700 pulses in a 600 μs long burst, i.e. 4.5 MHz intra-burst repetition rate.

- Pulses delivered to the laser tables at the experiments of sub-20 fs to sub-100 fs duration (depending on experimental conditions), around 800 nm wavelength, up to 200 µJ energy at 4.5 MHz repetition rate, and higher energy (> 1 mJ) at lower repetition rate.
- Low repetition rates, single-shot operation, and arbitrary intra-burst patterns are also desirable.
- High-energy (> 100 mJ) picosecond and nanosecond pulses should be available.
- Frequency conversion and tunability are important for nearly all experiments. Individual solutions will be worked out together with the instrument scientists in due course.

Apart from the pump-probe laser, the High Energy Density (HED) instrument at SASE2 will also be equipped with a commercial 100 TW-class Ti:sapphire (titanium-sapphire) laser. Planning, procurement, and integration will be synchronized with the planning for the HED instrument.

Approach

There are two principle pathways to MHz repetition rate, ultrashort-pulse, burst mode laser specifications with burst average power at the kW level: synchronously pumped, cryogenically cooled multi-pass Ti:sapphire amplifiers and optical parametric chirped-pulse amplifiers (OPCPA).

Both schemes ultimately benefit from 10 kW-level burst average power, green, nanosecond/picosecond pump lasers to pump the amplifiers in synchronicity with the seed. The Laser group decided to pursue the OPCPA option in a non-collinear optical parametric amplifier (NOPA) configuration. Major reasons included cost as well as the shorter achievable pulse width and greater flexibility.

After the requirement analysis, the Laser group embarked on an ongoing conceptual design phase for the pump-probe laser during which different options for the front-end design, the high-power picosecond burst mode amplifier, and the NOPA were considered.

Front-end design

The front end will consist of two fibre amplifier chains, seeded at 1030 nm by a free-space-coupled femtosecond soliton oscillator. One amplifier chain will be used for the generation of a synchronized super-continuum to seed the first NOPA stage, while the other will seed the burst mode power amplifier. Various switching elements will allow operation at different repetition rates with pulse energies scaling accordingly.

A simulation code for short-pulse and chirped-pulse propagation in fibre amplifier systems was developed, including all relevant linear and nonlinear effects. During system design, this proved to be a valuable tool to support design decisions.

The front end was designed in collaboration with industry and ordered. Delivery is expected in the first half of 2012.

The benefits and drawbacks of all currently known schemes for scaling solid-state laser amplifiers to very high power were juxtaposed, taking into account the specific requirements for the European XFEL.

20 kW, 1030 nm picosecond burst mode power amplifier

The benefits and drawbacks of all currently known schemes for scaling solid-state laser amplifiers to very high power were juxtaposed, taking into account the specific requirements for the European XFEL pump-probe laser and, in particular, the time line. These schemes included ytterbium fibre amplifiers; room temperature Yb:YAG (ytterbium-doped yttrium aluminium garnet) thin-disk amplifiers; cryogenically cooled Yb:YAG amplifiers; and Yb:YAG InnoSlab amplifiers. As a result, the approach based on the InnoSlab Yb:YAG slab amplifier technology, developed at the Fraunhofer Institute for Laser Technology in Aachen, Germany, was found to be the most promising.

A comprehensive feasibility study was carried out in conjunction with industry to identify the most practical and economic system design for a 20 kW Yb:YAG InnoSlab burst mode amplifier.

After reaching the final design and specifications, a staged development plan was agreed on with industry. The close collaboration foresees the first deliverable system in mid-2012 and the final 20 kW system at the end of Q1 in 2013.

NOPA

One advantage of optical parametric amplification over the use of a classical laser amplifier, such as Ti:sapphire, is the simultaneous scalability of average and peak power while maintaining a compact footprint. To this end, we have looked for NOPA configurations that can accommodate the pulse width, energy, and repetition rate requirements of the European XFEL pump-probe laser.

We developed a simulation code for NOPAs, including all relevant linear and nonlinear effects. Testing and benchmarking is ongoing. First results indicate the code’s usefulness in NOPA design.

We studied the feasibility of various nonlinear amplifier crystals for NOPAs: bismuth triborate (BIBO), lithium triborate (LBO), beta-barium borate (BBO), and potassium dihydrogen phosphate (KDP). For experiments in 2012 and 2013, we chose two multi-stage designs with BBO as well as a mixed BBO–LBO design.

We evaluated the relative simplicity and flexibility of various dispersion management schemes for short-pulse delivery to the experiments.

The laser development for the European XFEL pump-probe laser is projected to take at least three and a half years. It will require substantial lab work for building, testing, and characterizing the various subsystems, the complete laser, and the pulse delivery schemes.

Laser Advisory Committee

The laser-related activities at user facilities such as the European XFEL and the Free-Electron Laser in Hamburg (FLASH) at Deutsches Elektronen-Synchrotron (DESY) are quite varied. They include development of commercially unavailable laser sources, procurement, installation of laser systems, establishment and maintenance of laser facilities for user operation, and interaction with instrument scientists and users before and during experiments. Given the importance of optical lasers for free-electron laser facilities, European XFEL and DESY decided to put these activities under the scrutiny of a common Laser Advisory Committee (LAC). European XFEL and DESY were able to appoint a panel of six world-renowned international experts for the LAC, which will convene for the first time in March 2012.

Laser development lab

The laser development for the European XFEL pump-probe laser is projected to take at least three and a half years. It will require substantial lab work for building, testing, and characterizing the various subsystems, the complete laser, and the pulse delivery schemes. However, since suitable lab space will not be available until the completion of the new European XFEL headquarters in Schenefeld, the Laser group has teamed up with the group of Franz X. Kärtner at the Center for Free-Electron Laser Science (CFEL) to invest in a dedicated laser development lab on the DESY grounds (Building 49d). Interior planning and procurement of equipment for this lab was nearly finished in 2011. Lab construction is in progress and is expected to be completed in May 2012.

Outlook for 2012

Major milestones and tasks for the Laser group in 2012 include:

- Occupation and operational completion of the laser development lab by mid-2012
- Commissioning of the front end and the first-stage deliverable of the high-power burst mode booster
- Start of experiments with super-continuum generation and NOPA
- Planning and start of realization of various subsystems of the pump-probe laser, such as beam pointing stabilization, timing stabilization, and pulse-on-demand
- Increasing the size of the group by up to four full-time employees

To nurture the synergies, the newly founded laser development groups at CFEL, DESY, and European XFEL are actively exchanging experience, and collaboration is fostered whenever possible and meaningful. ■

Group members
Mikhail Pergament, Cruz Mendez, Maximilian Lederer (group leader), and Martin Kellert

SAMPLE ENVIRONMENT

The ultrashort, high-intensity X-rays of the European XFEL will enable new science with a wide range of potential samples delivered in various forms into diverse environments. Providing the delivery methods and target systems that allow such a variety of samples to be studied using the fast repetition rate and high peak intensity of the European XFEL is the job of the Sample Environment group.

Unique challenges

Potential samples to be investigated at the European XFEL include atoms and molecules, free clusters, nanoparticles, and biological samples such as proteins, viruses, and cells. These samples can be free in vacuum, dissolved in liquids, or deposited on surfaces. Studies of bulk and surface properties of solid-state samples are also potential goals of science at the European XFEL.

The fast burst mode operation of the European XFEL and the high peak intensity set high demands on sample preparation. To use the full repetition rate of 27 000 light pulses per second, special care must be taken in the sample environment to prevent so-called “crosstalk”, in which the measurement of one pulse is influenced by previous pulses. In many cases, the sample needs to be renewed within 200 ns. Given the high peak intensity of the radiation, bulk samples can be destroyed with a single shot. Even if the sample survives the direct hit of the free-electron laser (FEL) radiation, space charges can influence the subsequent measurements if they are not removed quickly.

These challenges are common for many experiments at the six scientific instruments currently being designed for the European XFEL. Some of the sample delivery methods—such as delivering biological specimen into the vacuum and generating rare-gas and metallic clusters—will be needed at hard and soft X-ray instruments. For many samples, spectroscopic as well as imaging methods are expected to give complementary information. The Sample Environment group will set up projects to provide common sample delivery methods for all scientific instruments.

Establishing the Sample Environment group

The Sample Environment group was established in October 2011. The group’s task is to define sample environment standards at the European XFEL in close collaboration with the instrument scientists, supply the necessary common hardware and infrastructure, and provide in-house groups and users with service and advice. For the user community, the group will serve as a contact point to choose the right instruments and sample delivery methods for the experiments.

In 2011, we began to evaluate the demands placed on sample environment systems by instrument groups and external users at the European XFEL. Systems that are needed by a broad range of users will be either developed in-house or delivered as in-kind contributions from the shareholders. More specialized setups will be provided by user consortia. Here the Sample Environment group will ensure compatibility with all instruments. All sample delivery methods that are going to be developed for the European XFEL will be available to all users.

Setting up and operating user labs

Many experiments at the European XFEL will require special preparation and handling of samples. One of the tasks of the Sample Environment group will be the setup and operation of user labs that provide all the tools required to make experiments a success. In 2011, the group investigated the requirements of in-house research groups and external users for lab equipment. These requirements include chemical and biological preparation labs, clean workbenches for sample preparation and handling, as well as laminar-flow and glove boxes for sample handling under dust-free and inert-gas conditions. The group specified diagnostics tools for offline sample preparation. Optical and electron microscopy, X-ray diffraction, and electron spectroscopy setups are under consideration.

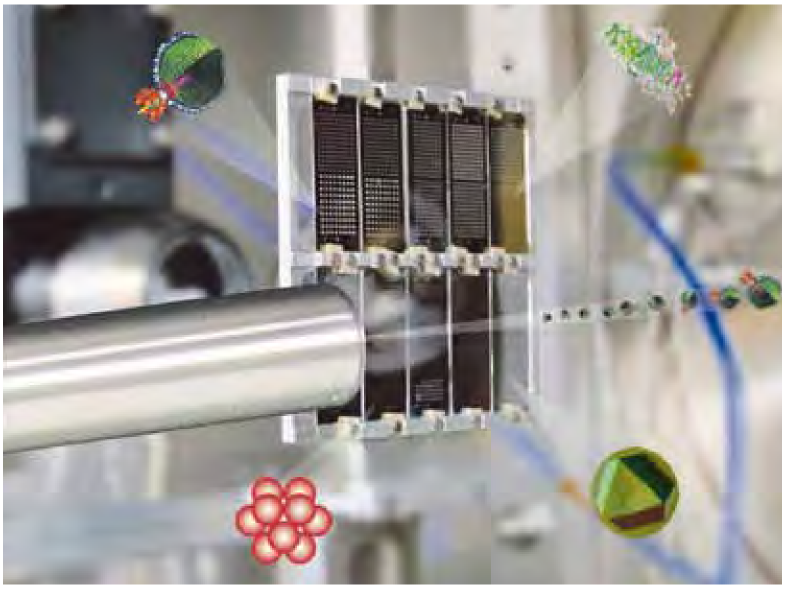


Figure 1 One of the activities of the Sample Environment group is to provide biological samples for imaging experiments. Those samples can be free in vacuum or deposited on silicon nitride windows.

For bio-imaging projects at the Single Particles, Clusters, and Biomolecules (SPB) instrument, it is essential to have access to state-of-the-art biological labs. The Sample Environment group is in contact with potential users with backgrounds in biology to explore their needs and expectations. The group also started to work on providing the necessary infrastructure. Users will have the opportunity to grow biological samples in European XFEL labs, process and prepare purified samples, such as crystals or cell organelles, and inject them into the SPB instrument for hard X-ray imaging and into the Small Quantum Systems (SQS) instrument for soft X-ray imaging.

To use the full repetition rate of 27 000 light pulses per second, special care must be taken in the sample environment to prevent so-called “crosstalk”, in which the measurement of one pulse is influenced by previous pulses. In many cases, the sample needs to be renewed within 200 ns.

Sample delivery for bio-imaging

In December 2011, the first in-kind contribution contract related to the Sample Environment group was signed by the Swedish Research Council (VR), Uppsala University in Sweden, and European XFEL. Janos Hajdu, an internationally renowned expert in structural biology, and his group at Uppsala University will develop and provide a sample injector system. The Sample Environment group was active in defining the design goals of the project to inject and focus aerosol samples into the vacuum of the SPB and SQS imaging end stations. This project is the first step towards 3D imaging of biological samples, such as protein complexes, virus particles, and cells. The European XFEL facility will be exceptionally well-suited to this research. The high repetition rate of the source will allow the measuring of full 3D data sets in just minutes, where other sources would require many hours. Combined with state-of-the-art reconstruction methods, this project will provide a unique opportunity to study as-yet-unresolved biological structures.

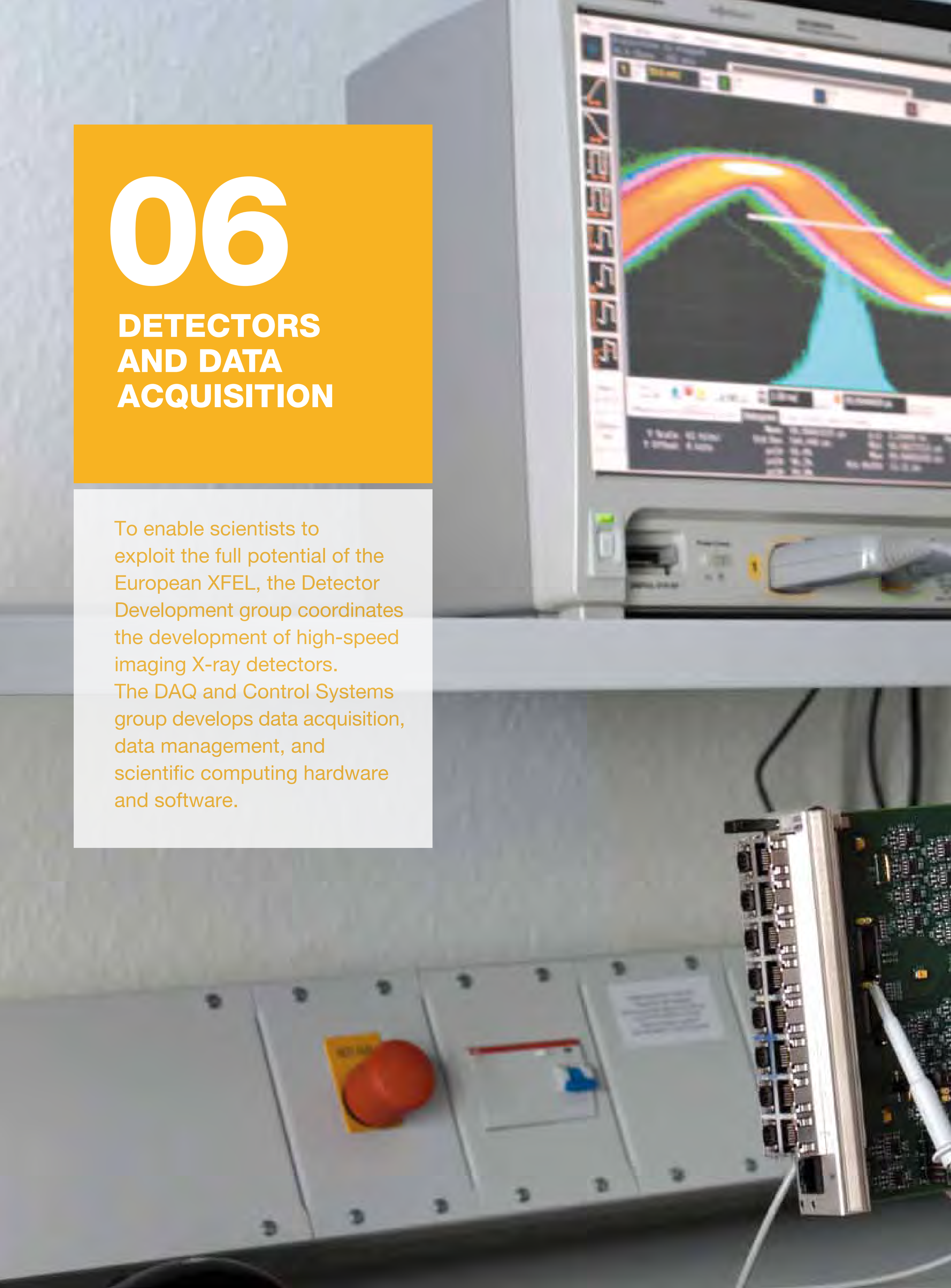
Further sample environment techniques

In addition to the simple gas inlet systems that will be standard parts of the scientific instruments, the Sample Environment group has begun to plan the development of special target systems for the investigation of aligned and oriented molecules, rare-gas and metal clusters, high-pressure gas targets, and so on.

Given the high repetition rate of the European XFEL, liquid-jet and droplet systems are of great importance. They provide a constant stream of dense matter that is renewed quickly enough to provide a fresh sample for every single shot. Solved targets, such as biosamples, can be transported by a liquid jet into the interaction region. But the jet itself can also be a valuable target for experiments in which high energy density is required or surface processes of liquids are under consideration.

For fixed targets such as magnetic structures, imaging objects on membranes, or surface chemistry, a rapid sample change is required. A sample change fast enough to exploit the burst mode of the facility could be reached using rotating disks. For precise positioning, it might be possible to change the sample fast enough for 10 Hz single-bunch operation only. The Sample Environment group is considering both options. Sample exchange methods will be identified and developed in collaboration with international partners. ■

Group members
Charlotte Uetrecht (guest researcher) and Joachim Schulz (group leader)



06
DETECTORS AND DATA ACQUISITION

To enable scientists to exploit the full potential of the European XFEL, the Detector Development group coordinates the development of high-speed imaging X-ray detectors. The DAQ and Control Systems group develops data acquisition, data management, and scientific computing hardware and software.

DETECTOR DEVELOPMENT

To enable scientists to exploit the full potential of the ultrafast burst mode of the European XFEL and record valuable data at the scientific instruments, high-speed imaging X-ray detectors are essential. The development of this highly specialized instrumentation is being coordinated—in close collaboration with national and international partners—by the Detector Development group. The main focus is high-speed large- and small-area detectors for imaging, monitoring, veto, and spectroscopic applications.

Building expertise and infrastructure

The Detector Development group was established in 2010 to coordinate the development of detectors and build up test and calibration infrastructure at the European XFEL facility. Currently, the group is focused on coordinating the development of ultrafast 2D pixel detectors for imaging experiments.

In 2011, three detector specialists joined the group. They are in charge of building the expertise and infrastructure needed to develop, calibrate, commission, and operate detector systems in collaboration with national and international consortia and industrial partners. Maintaining the detectors and developing new detector concepts will also become an integral part of their activities.

A temporary detector laboratory is presently under construction in a hall formerly used for one of the experiments at the DESY HERA accelerator. This laboratory will provide a clean, dust-free environment for performance and calibration tests until the new European XFEL headquarters building in Schenefeld becomes available.

The detector development activities require laboratory infrastructure for performance, calibration, and commissioning tests of prototype detectors and data acquisition (DAQ) components. A temporary detector laboratory is presently under construction in a hall formerly used for one of the experiments at the HERA accelerator of Deutsches Elektronen-Synchrotron (DESY). This laboratory will provide a clean, dust-free environment for performance and calibration tests until the new European XFEL headquarters building in Schenefeld becomes available. The group expects that first detector test setups will be operational by the end of 2012. A small prototype system of the Large Pixel Detector (LPD) is expected to be one of the first devices to be delivered to European XFEL for performance optimization towards the end of 2012.

Withstanding high-intensity X-ray radiation

The full burst mode of the European XFEL requires detectors based on sensor and application-specific integrated circuit (ASIC) technology that can withstand intense X-ray free-electron laser (FEL) radiation over several years. Radiation damage caused by X-ray photons can diminish detector performance. Such degradation effects can accumulate over the lifetime of a detector. To push the lifetime of the imaging detectors to the radiation tolerance level required for the European XFEL, a careful design of silicon sensors and ASICs is necessary. In parallel, design optimizations and radiation tolerance measurements are essential to verify new design concepts. In 2011, prototype sensors and ASICs for the three types of detectors being developed for European XFEL—Adaptive Gain Integrating Pixel Detector (AGIPD), Depleted P-Channel Field Effect Transistor (DEPFET) Sensor with Signal Compression (DSSC), and LPD—have been continuously tested for their radiation "hardness". The outcome of these tests provides valuable feedback for sensor and ASIC designers to further optimize their circuit technology.

From ideas to devices

At the 9th and 10th meetings of the European XFEL Detector Advisory Committee (DAC) in April and October 2011, respectively, two projects faced a "go/no go" milestone, including an in-depth review of their project progress:

- **LPD project**
  Managed by the detector group of the Rutherford Appleton Laboratory (RAL) and carried out in conjunction with the University of Glasgow, both in the UK
- **DSSC project**
  Managed by the MPI Halbleiterlabor (MPI HLL) in Munich, Germany, with contributions from DESY Hamburg, Politecnico di Milano in Italy, Ruprecht-Karls-Universität Heidelberg in Germany, Università degli Studi di Bergamo in Italy, and Universität Siegen in Germany

These early milestones were fixed in the contracts with all detector consortia to enable flexibility in deciding whether to continue a particular development, depending on the progress reported.

Both projects passed the review and were encouraged by DAC to continue towards the realization of one megapixel (1 Mpx) devices and their final installation in the scientific instruments. In passing this major milestone, the projects took an important step towards signing new contracts with European XFEL. These contracts will cover the transition phase from mere development to the final delivery and installation of the detectors.

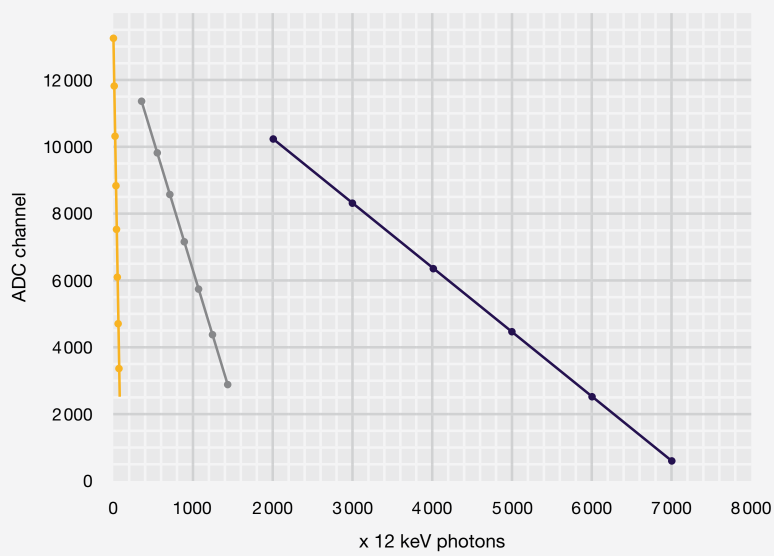


Figure 1 Proof of principle for the multiple-gain concept of the AGIPD sensor. The result shows the linear characteristics of the three amplification levels of the sensor for low, medium, and high photon intensities.
Left to right Characteristics of the high-gain (orange), medium-gain (grey), and low-gain (violet) stages.

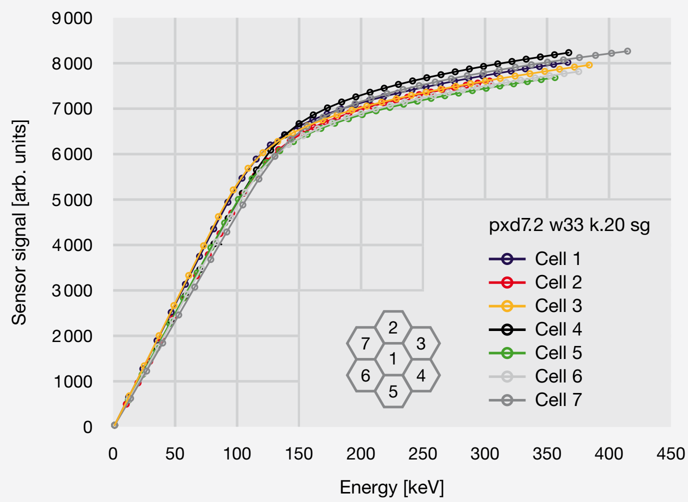


Figure 2 Proof of principle of the nonlinear response of the DSSC sensor. The amplification characteristics of a matrix of seven pixel cells have been measured. The results show the nonlinear behaviour of the pixels cells for high photon intensities and the homogeneity of the gains of different pixel cells.

Progress of AGIPD, DSSC, and LPD consortia

In 2011, all three detector consortia showed good progress in various areas.

Performance measurements of all functional building blocks of the AGIPD ASIC showed that their design is capable of achieving the expected system performance and functionality. Especially the verification of the gain switching concept was a major achievement on the way towards the final AGIP ASIC chip design (Figure 1).

The DSSC consortium successfully provided the proof of principle of its novel DSSC sensor technology, which implements a nonlinear response on the sensor level (Figure 2).

In close collaboration with the Femtosecond X-Ray Experiments (FXE) instrument group and the LPD consortium, a first detector mechanics concept for the 1 Mpx LPD detector and concepts for test systems were developed (Figure 3). The Mpx detector concept is optimized for the FXE scientific instrument, whereas the test systems will be used for performance characterization and DAQ tests.

In 2012, the Detector Development group will expand its skills and activities into mechanics, electronics, and software engineering. It will also join forces with the DAQ and Control Systems group to build a common electronics development laboratory. The full burst mode of the European XFEL requires detectors that can withstand intense X-ray free-electron laser radiation over several years.

Figure 3 Mechanics concept of a quadrant (¼ Mpx) LPD system, designed for detector performance and calibration tests

Looking forward to 2012

In the coming year, the Detector Development group will expand its skills and activities into mechanics, electronics, and software engineering. The group is presently recruiting several engineers who will take over key roles when detectors are integrated into the scientific instruments. Joining forces with the DAQ and Control Systems group in the near future to build a common electronics development laboratory will further strengthen the Detector Development group.

In 2012, the group will face several exciting challenges. European XFEL will receive the first detector prototype, and the group will build up test and calibration infrastructure. Additional major milestones are the extension of the contracts with the DSSC and LPD consortia. The group looks forward to contributing to the technical designs of the Small Quantum System (SQS), the Femtosecond X-Ray Experiment (FXE), the Single Particles, Clusters, and Biomolecules (SPB), and the Materials Imaging and Dynamics (MID) scientific instruments.

Group members
Andreas Koch, Monica Turcato, Patrick Gessler (see also DAQ and Control Systems group), Jolanta Sztuk-Dambietz, and Markus Kuster (group leader)

DAQ AND CONTROL SYSTEMS

In collaboration with international partners and other European XFEL groups, the DAQ and Control Systems group develops the data acquisition (DAQ), data management (DM) and scientific computing (SC) hardware and software required to operate photon beamlines and experiments as well as facilitate data analysis. The objectives defined in the 2009 computing technical design report (TDR) were steadily implemented throughout 2011.

Accelerated development

In 2011, the increase in manpower allowed the fine structure in DAQ and DM activities to be addressed. The creation of an electronics subgroup in collaboration with the Detector Development group accelerated development of synchronization and data readout electronics, and significantly improved the group's capabilities regarding usage and programming of field-programmable gate arrays (FPGAs). FPGA programming is particularly important due to the prominence of FPGA usage in real-time data processing and readout devices and combines well with the decision to use the telecommunications computing architecture xTCA crate and board standards for electronics developments.

Large-area cameras of 1k x 1k and above are perhaps the most important scientific detection instruments to be used at the European XFEL. Because of the demanding timing and detection requirements, custom detector and DAQ developments are needed.

A review of beamline control systems used at other light sources led to the decision to implement the automation process control required by beamlines and experiments with the Ethernet for Control Automation Technology (EtherCAT) bus standard manufactured by Beckhoff GmbH. A subgroup was formed to coordinate and drive this activity. The review also confirmed the decision to continue the development of a software framework to answer all control, data management, and scientific computing requirements. The development of a homogeneous software framework for control and data management launched in 2010 was extended with the creation of a subgroup responsible for the development of the framework elements associated with analysis. In 2011, the group submitted a number of proposals to European Union (EU) and German–Russian agencies for additional project-related funding. Two projects related to DAQ and DM have so far been accepted for funding within the Cluster of Research Infrastructures for Synergies in Physics (CRISP) EU call.

DAQ

The collaboration with University College London (UCL) and the Science and Technology Facilities Council (STFC) has continued to develop the sequencing and readout systems, respectively, to be used with the large-area cameras being designed by the AGIPD, DSSC, and LPD consortia (see the “Detector Development” article) to operate at the European XFEL. Large-area cameras of 1k x 1k and above are perhaps the most important scientific detection instruments to be used at the European XFEL. Because of the demanding timing and detection requirements, custom detector and DAQ developments are needed. The clock and control sequencing system is required to interface to the linear accelerator (linac) timing system; generate and distribute fast signals, clock signals, and veto signals to the front-end readout interfaces (RIs) of the cameras; receive error signals; and ensure system synchronicity. The train builder readout system is required to receive image fragments from camera front-end modules, reorganize them into complete trains of pulse-ordered frames, perform signal processing, and send train data to the downstream computing layer (PC layer). An important feature of both developments is the large-scale use of FPGAs for digital signal processing on electronics boards hosted in telecommunications computing architecture (TCA) industrial standard crates.

The delivery of prototype clock and control rear transition module (RTM) boards in December 2011 allowed a complete one-megapixel (1 Mpx) large-area camera sequencing system to be assembled into a microTCA (MTCA.4) crate for laboratory testing. The system consists of a DESY advanced mezzanine card (DAMC2) FPGA digital front board, a clock and control rear board, an X-ray free-electron laser (FEL) timing receiver (TR) system board, and a crate central processing unit (CPU). The TR distributes linac timing and configuration information over the backplane to the DAMC2, where FPGA firmware modules generate and control signals sent to the RTM for distribution to the camera front-end modules. The physical arrangement of the DAMC2 and RTM boards in the crate is shown in Figure 1. The upper and lower connectors facilitate RTM-DAMC2 and DAMC2-TR-CPU communication, respectively.

The train builder readout system is significantly more complicated and larger in terms of components than the sequencer system; consequently, it is developed using the large-board advanced TCA (ATCA) crate standard. Difficulties in the layout design of the large number of components present and in routing the connections between them delayed delivery of the first prototypes. First boards are now expected for testing in mid-2012. Both synchronization and train builder developments will be tested in the slice test referred to below.

During 2011, it became clear that the original design of the veto system, which concentrated on reducing the impact of limitations in the number of frames that can be acquired per train by large-area cameras, could be generalized in scope to allow control of rejecting poor-quality pulse data in all detectors associated with an experiment. The updated specification foresees that all custom front-end detector device interfaces allow data rejection on receiving a veto signal. A schematic of the updated veto system is shown in Figure 2. The hardware implementation follows the MTCA.4 standard, and a DAMC2 digital board will be used to receive, evaluate, dispatch, and veto source and user information between the participating systems using low-latency serial links.

A number of other DAQ projects were started or continued in 2011: a single-crate DAQ system for avalanche photodiode (APD) 4.5 MHz bunch readout and control, an initial definition of timing and DAQ interfaces for pump laser systems, a timing signal distribution for commercial screen monitoring cameras, DAQ interfaces and requirements for photoelectron spectrometers, and the selection of a digitizer standard based on MTCA.4.

The formation of an electronics subgroup has significantly improved the group's capabilities regarding FPGA usage and firmware programming. A key task of the subgroup is to ensure that development work performed uses defined standards (for example, framework, local buses, coding standards, and documentation) and that developments are reusable.

Figure 1 Sequencing RTM (left) and DAMC2 MTCA.4 (right) prototype boards

Control

In spring 2011, the DAQ and Control Systems group concluded a review of light source control systems at the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in California, the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, the ALBA Synchrotron Light Facility in Barcelona, Spain, the Paul Scherrer Institute (PSI) in Villigen, Switzerland, and the Diamond Light Source in Oxfordshire, UK, as well as the Free-Electron Laser in Hamburg (FLASH) and the PETRA III light source at Deutsches Elektronen-Synchrotron (DESY), Germany.

The principal observation regarding control software was that most control systems standardize software–hardware communication (for example, TANGO and DOOCS), image processing and handling (for example, CCP4, Phenix, and Eman), as well as scientific workflows (for example, Triana and Kepler). However, no system provided a single homogenous solution for all the functional requirements. Creating a control system by compounding different top-level software packages is difficult and leads to non-uniform software; it was decided to build the top layer in-house, carefully learning from others and preparing to interface important systems.

In spring 2011, the DAQ and Control Systems group concluded a review of light source control systems at LCLS, ESRF, CELLS–ALBA, PSI, Diamond Light Source, FLASH, and PETRA III.

The review of control functionality for non-DAQ beamline and scientific instruments showed a clear preference for the use of a commercial single-manufacturer Ethernet-based fieldbus system. This recommendation was followed, and the necessary programmable logic controller (PLC) and device connection layers are being implemented using the EtherCAT system developed by Beckhoff GmbH.

Data management and homogeneous software framework

The DM concept and policies, as well as the major services required, are described in the computing TDR, which was released in October 2009. The data access model currently envisaged for the European XFEL is that the bulk of experiment data is analysed on site, close to the data storage system in computing clusters with batch job submission and data organization tools developed in the context of the European e-Infrastructure initiative. Lightweight client access is foreseen to allow small amounts of data to be transferred over a wide area network (WAN) to home institutes for final analysis or algorithm tuning.

The key components of the DM system, as well as its characteristics and functionality, can be summarized as follows:

- Secure tape archive will be used for long-term data storage.
- Data from unsuccessful experiment runs will not be stored, and filtering of bad data will be applied as early as possible.
- Data compression will be applied whenever possible.
- Raw data stored in the archive will remain immutable.
- Disk storage system (dCache) will be used as the front end to the tape archive.
- Data archive and disk cache system will be integrated with the e-Infrastructure.
- Computing clusters close to the data archive will be used for offline data analysis.
- Data will be protected using global authentication and authorization services.
- Metadata services will be used to describe the content of the archive.
- Grid services will be provided for transferring data to offsite locations.
- User-friendly interfaces will be provided to access data and metadata services remotely.

The following policy decisions relating to DM usage were defined:

- Initial size of the data storage system will be 10 PB.
- Data will be archived for at least one year before deletion.
- Reasonable amount of archive storage will be provided to experiments.
- Reasonable amount of computing power will be provided to experiments.

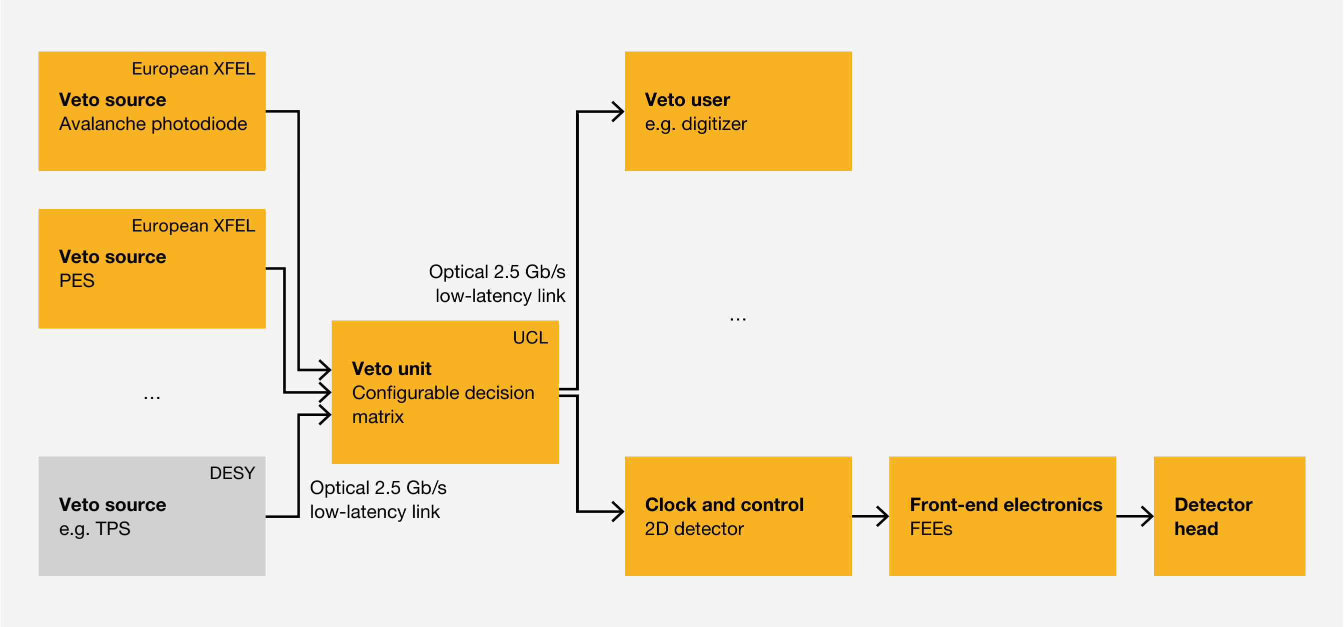


Figure 2 Schematic showing the generalized veto system

Development of the homogeneous software framework covering control, data management, and scientific processing continued throughout the year. Software design and implementation uses C++, Boost, Python, and PyQt as core technologies and integrates high-quality libraries (for example, Qt, OpenMQ, Log4cpp, TinyXML, and Cimg). Using the development environment defined in 2010, the design and implementation of toolkit components common to all software requirements were targeted: memory-object management, configuration, logging, network services, error handling, Python binding, databases, graphical user interface (GUI), plug-in mechanism, cross-platform building, and installation systems.

Initial tests of the control and data management software were successfully performed during the second half of 2011.

Development of the homogeneous software framework covering control, data management, and scientific processing continued throughout the year. Using the development environment defined in 2010, the design and implementation of toolkit components common to all software requirements were targeted.

Scientific computing

In 2011, initial work on defining the scope of scientific computing was performed. This work was concentrated on designing and implementing data processing workflows (pipelines) within the software framework. Tests of these using single particle and biomolecule (SPB) data processing algorithms were made in collaboration with experts from experiment groups at the Center for Free-Electron Laser Science (CFEL), LCLS, and European XFEL.

Outlook for 2012

A full test of most aspects of the software framework and associated hardware systems will be made during 2012, when the so-called “slice test” goes online. Hardware is currently being purchased to implement a 1 Mpx wide slice of the five-layer data architecture defined in the 2009 computing TDR. This includes data injection from the train builder prototype boards, data processing and aggregation on the PC layer, data storage into the online disk cache and offline disk and tape storage systems, and cluster-based CPU and graphics processing unit (GPU) data processing. In parallel, work on DAQ, electronics, and beamline and experiment control systems will continue.

Group members
Kerstin Weger, Burkhard Heisen, Christopher Youngman (group leader), Andrea Parenti (since March 2012), Bruno Fernandes, Bartosz Poljancewicz (IT), Nicola Coppola, Krzysztof Wrona (IT group leader), Janusz Szuba, Jorge Elizondo (since February 2012), Patrick Gessler (see also Detector Development group), Djelloul Boukhelef, Manfred Knaack (IT), Irina Kozlova, Sergey Esenov, and Olivier Batindek

07

FACTS, FIGURES, AND SERVICES

The European XFEL benefits from collaborations with laboratories, scientific institutions, and universities worldwide. The facility also requires a highly professional staff and administrative infrastructure. In 2011, international recruiting resulted in a 61% increase in the number of employees.


19

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

AT A GLANCE

The European XFEL is a research facility that will open up new research opportunities for science and industry. Currently under construction in Hamburg and Schleswig-Holstein in northern Germany, the 3.4 km long X-ray free-electron laser (FEL) will generate ultrashort X-ray flashes for photon science experiments with a peak brilliance that is a billion times higher than that of the best synchrotron X-ray radiation sources.

Brilliant light for new research opportunities

With a repetition rate of 27 000 pulses per second and an outstanding peak brilliance, the European XFEL facility will produce ultrashort X-ray flashes that will allow researchers to map the atomic details of viruses, decipher the molecular composition of cells, take three-dimensional images of the nanoworld, film chemical reactions, and study processes like those occurring deep inside planets.

The European XFEL will be located mainly in tunnels 6 to 38 m underground with inner diameters of up to 5.3 m, roughly the diameter of the new U4 subway tunnels in Hamburg, which were dug with the same type of tunnel boring machine. As shown in Figure 1, the 3.4 km long facility will run from the Deutsches Elektronen-Synchrotron (DESY) research centre in Hamburg to the town of Schenefeld in the German federal state of Schleswig-Holstein. The new facility will comprise three sites: the DESY-Bahrenfeld site with the injector complex, the Osdorfer Born site with one distribution shaft, and the Schenefeld campus site, which will host the underground experiment hall with a large laboratory and office building on top. The latter will serve as the company headquarters.

European XFEL GmbH

As of December 2011, 12 countries are participating in the European XFEL project: Denmark, France, Germany, Greece, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden, and Switzerland. The international partners have entrusted the construction and operation of the European XFEL facility to the non-profit European X-Ray Free-Electron Laser Facility GmbH, which was established in October 2009 as a limited liability company under German law. When user operation starts in 2016, the company will employ about 250 people.

Construction costs

The European XFEL is a joint effort of many partners, among them the DESY research centre and other organizations worldwide. Construction started in early 2009. The beginning of commissioning is planned for 2015. User operation with one beamline and two instruments will start in 2016.

The construction costs, including commissioning, amount to 1.1 billion euro (at 2005 price levels). Higher costs for underground civil construction as well as a reduction of anticipated contributions from some countries caused a funding gap in 2011. Following a joint initiative from Germany, Russia, and other countries, the gap will be closed and the percentage of shares recalculated accordingly. This process is expected to be completed in 2012. Currently, the host country, Germany (federal government, city-state of Hamburg, and state of Schleswig-Holstein), covers 54% of the costs. Russia covers 23% and each of the other international shareholders between 1% and 3.5%. To a great extent, the European XFEL facility will be realized by means of in-kind contributions by shareholders and partners. ■

SHORT HISTORY OF EUROPEAN XFEL

In the 1990s, Deutsches Elektronen-Synchrotron (DESY) and international partners developed a proposal for a new research institution in the Hamburg area: a large-scale facility comprising a linear collider for particle physics and an X-ray free-electron laser (FEL) for photon science. The X-ray FEL part of the project, as a European facility to be implemented in collaboration with other countries, got the go-ahead from the German Ministry of Education and Research (BMBF) in 2003. The new research institution was formally established in late 2009 with the signature of the intergovernmental Convention by an initial group of 10 countries and the foundation of the European X-Ray Free-Electron Laser Facility GmbH, a non-profit limited liability company under German law in charge of the construction and operation of the European XFEL facility.

1980–1984

The idea of a single-pass FEL for short wavelengths is introduced in the independent work of A. M. Kondratenko and E.L. Saldin (1980), and of R. Bonifacio, C. Pellegrini, and L.M. Narducci (1984). The latter authors coin the term "self-amplified spontaneous emission", or "SASE", to describe the amplification process on which the European XFEL will eventually rely.

1992

In an international collaboration at a test facility at DESY, scientists begin to develop and test the technology for the Tera-Electronvolt Energy Superconducting Linear Accelerator (TESLA) project. This technology will eventually form the basis for the European XFEL.

1997

The international TESLA collaboration led by DESY publishes a conceptual design report (CDR) for TESLA, a linear collider with an integrated X-ray laser facility.

Figure 1 Experiment section of the TESLA test facility at DESY in 1997

2000

Scientists at the TESLA test facility at DESY achieve a world first by generating shortwave laser light in the ultraviolet range (80–180 nm) using the pioneering SASE FEL principle on which the European XFEL is based.

Figure 2 Accelerator section of the TESLA test facility at DESY in 1999

Figure 3 On 22 February 2000, the free-electron laser at the TESLA test facility produced a laser beam for the first time—with the shortest wavelengths ever generated by a free-electron laser.

2001

The TESLA collaboration publishes a technical design report (TDR) for TESLA.

The FEL at the TESLA test facility demonstrates the greatest possible light amplification at 98 nm. A user programme with first experiments starts soon afterwards.

2002

A TDR for an X-ray laser laboratory with a dedicated linear accelerator in a separate tunnel is published as a supplement to the TESLA TDR.

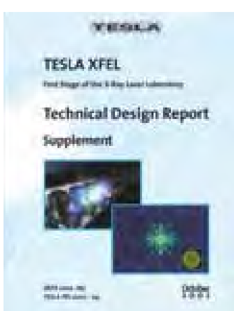


Figure 4 Supplement to the TESLA TDR

2003

The German government decides to cover around half of the investment costs for the dedicated X-ray laser facility described in the TESLA TDR supplement, provided the rest is borne by European partner countries. This decision leads to intense negotiations on funding and participation.

A site near DESY is chosen for the new X-ray laser facility, so it can make use of existing DESY infrastructure.

The 100 m long TESLA test facility is extended to a total length of 260 m and modified into an FEL user facility for photon science experiments with vacuum-ultraviolet and soft X-ray radiation.

2004

The German federal states of Hamburg and Schleswig-Holstein ratify a treaty that provides the legal basis for the construction and operation of the X-ray laser facility. Among other things, the states agree on a joint public planning approval procedure, including an environmental impact assessment.

Figure 5 On 29 September 2004, Schleswig-Holstein's Minister President Heide Simonis (right) and Hamburg's Mayor Ole von Beust sign a state treaty that provides the legal basis for the construction and operation of the X-ray laser.

2005

At the beginning of the year, nine countries—France, Germany, Greece, Italy, Poland, Spain, Sweden, Switzerland, and the UK—sign a Memorandum of Understanding (MoU) in which they agree to work jointly on a governmental agreement for the construction and operation of the X-ray laser facility. Together with Denmark, Hungary, the Netherlands, Russia, Slovakia, and the European Union (EU), whose representatives are present as observers, the signatory countries form an International Steering Committee (ISC) that coordinates the preparations for the construction of the X-ray laser. By the end of the year, the MoU has also been signed by China, Denmark, Hungary, and Russia.

User operation begins at the new 260 m long DESY FEL facility, which is also used for studies and technological developments related to future projects, such as the European XFEL. Soon afterwards, the facility, which has been setting new records for the shortest wavelength ever produced with an FEL, is renamed the "Free-Electron Laser in Hamburg", or "FLASH".

Figure 6 On 27 April 2005, DESY directors Jochen Schneider (centre) and Albrecht Wagner (right) hand over the planning documents for the European XFEL project and the application letter initiating the public planning approval procedure to Friedhelm Wiegel, the representative of the State Authority for Mining, Energy and Geology of Lower Saxony.

2006

In July, the DESY XFEL project group and the European XFEL project team, established in Hamburg through the MoU, publish a TDR for the proposed European XFEL facility. In 580 pages, 270 authors from 69 institutes in 17 countries describe all of the scientific and technical details of the research facility.

In August, the State Authority for Mining, Energy and Geology (LBEG) of Lower Saxony, which is in charge of the public planning approval procedure for the European XFEL, gives the formal go-ahead for the realization of the facility.

In October, the European Strategy Forum on Research Infrastructures (ESFRI) committee of the EU publishes the first European roadmap for new large-scale research infrastructures. The European XFEL facility is among the first of the 35 projects on the list to proceed to the construction phase.

Figure 7 On 25 July 2006, representatives of European XFEL and DESY hand over the European XFEL TDR to the chairman of the International Steering Committee (ISC).
Left to right Jochen Schneider, Albrecht Wagner, Hermann Schunck (BMBF), Massimo Altarelli, Karl Witte, Andreas S. Schwarz, Reinhard Brinkmann, and Thomas Delissen

2007

In January, 260 scientists from 22 countries meet at DESY in Hamburg for the first European XFEL User Meeting.

In June, the German research ministry officially launches the European XFEL. Germany and the 12 interested partner countries—China, Denmark, France, Greece, Hungary, Italy, Poland, Russia, Spain, Sweden, Switzerland, and the UK—agree to construct a startup version of the facility, comprising 6 of 10 scientific instruments, with the aim to upgrade it as soon as possible to the complete facility with 10 instruments. The launch signals the start of the calls for tender for civil construction.

In July, the four-year Pre-XFEL project is launched. This project is funded by the EU and designed to support the foundation of the European XFEL as a major new research institution in Europe. The main purpose of the project is to provide all technical, legal, and financial documents necessary for the foundation of a company to build and operate the European XFEL facility. Other Pre-XFEL activities include recruiting international staff, informing potential users about the European XFEL, and facilitating the specification, research and development, prototyping, and industrialization required to build the technical infrastructure and components for the facility

In October, Slovakia officially joins the European XFEL project by signing the MoU.

Figure 8 The European XFEL is officially launched on 5 June 2007.
Left Valérie Pécresse, French Minister of Higher Education and Research; Peter Harry Carstensen, Minister President of Schleswig-Holstein; Annette Schavan, German Federal Minister of Education and Research; Ole von Beust, Mayor of the City of Hamburg; and Andrej A. Fursenko, Minister of Education and Science of the Russian Federation
Right Annette Schavan, Ole von Beust, and Peter Harry Carstensen

2008

In September, the European XFEL International Steering Committee (ISC) adopts the contents of the “Convention concerning the Construction and Operation of a European X-ray Free-Electron Laser Facility”, the legal foundation of the European XFEL GmbH.

In December, contracts are awarded for civil engineering works at the three European XFEL sites: Schenefeld (Schleswig-Holstein), Osdorfer Born (Hamburg), and DESY-Bahrenfeld (Hamburg).

Figure 9 Signing of the building contracts for the three underground construction lots for the European XFEL facility on 12 December 2008

Figure 10 In 2008, European XFEL moved into its current headquarters at Albert-Einstein-Ring 19, near the DESY site.

2009

In January, construction of the European XFEL facility officially starts in Schenefeld, Osdorfer Born, and DESY-Bahrenfeld.

In October, the European X-Ray Free-Electron Laser Facility GmbH is officially registered in the Hamburg commercial register.

In November, representatives from 10 partner countries—Denmark, Germany, Greece, Hungary, Italy, Poland, Russia, Slovakia, Sweden, and Switzerland—sign the European XFEL Convention and Final Act in the Hamburg city hall, thus establishing the European XFEL GmbH.

Figure 11 On 30 November 2009, representatives from 10 partner countries sign the European XFEL Convention and Final Act.
Left to right Mauro Dell'Ambrogio, State Secretary, State Secretariat for Education and Research, Switzerland; Peter Honeth, State Secretary, Ministry of Education and Research, Sweden; Andrej A. Fursenko, Minister of Education and Science of the Russian Federation; Prof. Jerzy Szwed, Undersecretary of State, Ministry of Science and Higher Education, Poland; Ole von Beust, Mayor of Hamburg; Giuseppe Pizza, State Secretary, Ministry for Education, Universities and Research, Italy; Prof. Frieder Meyer-Krahmer, State Secretary, Federal Ministry for Education and Research, Germany; Dr. Peter Ammon, State Secretary, Federal Foreign Office, Germany; Prof. Mikulás Supín, Director General, Division of Science and Technology, Ministry of Education of the Slovak Republic; Dr. Christos Vasilakos, Representative of the General Secretariat for Research and Technology in the Permanent Delegation of Greece at the European Union; István Varga, Minister for National Development and Economy, Hungary; Hans Müller Pedersen, Deputy Director General of the Danish Agency for Science, Technology and Innovation; and Peter Harry Carstensen, Minister President of Schleswig-Holstein

2010

In February, France signs the European XFEL Convention and Final Act, thereby bringing the number of partner countries to 11.

In May, European XFEL and DESY sign a long-term agreement on future collaboration. DESY has played an important role in fostering the X-ray laser project. It advanced the funding for the preparatory work and hosted the European XFEL project team. DESY will continue to provide administrative services and lead the international Accelerator Consortium that is constructing the 1.7 km long superconducting accelerator, including the electron source. After completion, DESY will take over the operation of the accelerator on behalf of European XFEL.

In July, the first tunnel boring machine powers up and construction of the tunnels for the European XFEL begins.

By the end of the year, Denmark, Germany, Poland, Russia, Slovakia, and Sweden have appointed shareholders to join the European XFEL GmbH. (For a complete list of shareholders, see “Shareholders” later in this chapter.)

Figure 12 First tunnel and borer christening ceremony on the European XFEL construction site Schenefeld on 30 June 2010

2011

In January, the second tunnel boring machine for the European XFEL starts drilling the photon tunnels beneath the Schenefeld campus.

In June, the first topping-out ceremony for one of the underground buildings of the European XFEL facility is celebrated on the DESY-Bahrenfeld construction site.

Scientists demonstrate that the parameters of the X-ray flashes generated by the new facility can be improved beyond the original design, based on research at SLAC National Accelerator Laboratory (USA) and DESY in Zeuthen.

At the end of the month, the Pre-XFEL project is officially concluded. All remaining duties and tasks are officially handed over to the European XFEL GmbH.

In July, the first tunnel boring machine reaches its final destination on the DESY-Bahrenfeld site, thereby completing the 2010 m long tunnel for the accelerator.

In October, Spain signs the European XFEL Convention and Final Act, thereby bringing the number of partner countries to 12.

Figure 13 First tunnel boring machine after its arrival in the final shaft

COOPERATION

Since its foundation, European XFEL has established an extensive international network with research organizations around the world. Through cooperations, programmes, and partnership agreements with leading researchers, it seeks to further advance X-ray laser science and allow scientists to prepare for the unique research opportunities at the European XFEL facility. In 2011, we signed a number of new agreements (see Chapter 1, "News and Events") and intensified established collaborations.

Cooperations with research institutions

CLPU

European XFEL and the Spanish Center for Ultrashort Ultraintense Pulsed Lasers (CLPU) in Salamanca cooperate to develop new ultrafast optical lasers to analyse physical and chemical processes in conjunction with the X-ray beams of the European XFEL. In combination with the unique features of the European XFEL, new optical laser technologies will enable scientists to film ultrafast processes, such as chemical and biochemical reactions that provide a basis for the development of more efficient industrial production processes or new medical products and devices. A Memorandum of Understanding (MoU) was signed on 10 October 2011. Based on this agreement, an optical laser expert from CLPU joined the European XFEL Optical Lasers group for a period of five months.

Figure 1 Representatives from CLPU and European XFEL sign a MoU on 10 October 2011. **Left to right** Thomas Tschentscher, Scientific Director, European XFEL; Luis Roso, Director, CLPU; Massimo Altarelli, Managing Director, European XFEL; Maximilian Lederer, Group Leader, Optical Lasers Group, European XFEL; and Karl Witte, Administrative Director, European XFEL

DESY

The relationship between European XFEL and its main shareholder, Deutsches Elektronen-Synchrotron (DESY) in Germany, is unique. The two partners collaborate on the construction, commissioning, and eventual operation of the facility, based on a long-term agreement.

EMBL

European XFEL cooperates with the European Molecular Biology Laboratory (EMBL), Europe’s top address for biological research on the molecular level. An MoU was signed on 12 September 2011.

Figure 2 Signing of the MoU between EMBL and European XFEL on 12 September 2011
Left to right Karl Witte, Administrative Director, European XFEL; Massimo Altarelli, Managing Director, European XFEL; Iain Mattaj, Director General, EMBL; and Matthias Wilmanns, Head of EMBL Hamburg

Helmholtz-Zentrum Berlin

An MoU for a collaboration was signed on 11 March 2010 by European XFEL and Helmholtz-Zentrum Berlin (HZB) in Germany. The goal is to establish specific collaborations to develop optical components in soft X-ray optics and diagnostics, especially with respect to the expertise at the BESSY synchrotron.

Kurchatov Institute

European XFEL cooperates with the NRC Kurchatov Institute in Moscow in calculating radiation parameters and organizing European XFEL schools for young scientists. The next school will be announced on the European XFEL homepage in autumn 2012.

LNLS

DESY, European XFEL, and the Brazilian synchrotron radiation laboratory (LNLS) in Campinas signed a cooperation agreement in Brasília on 5 May 2011.

Figure 3 Signing of a cooperation agreement in Brasília on 5 May 2011
Left to right José Roque da Silva, Director, LNLS; Christian Wulff, President of the Federal Republic of Germany; Dilma Rousseff, President of the Federal Republic of Brazil; Helmut Dosch, Chairman of the Board of Directors, DESY; and Massimo Altarelli, Managing Director, European XFEL

SLAC

Regular contacts with SLAC National Accelerator Laboratory in California provide an important opportunity to gain hands-on experience at an X-ray FEL in operation, the Linac Coherent Light Source (LCLS). An MoU was signed on 27 July 2009.

Southern Federal University

European XFEL and Southern Federal University in Rostov, Russia, stated their interest in establishing a joint programme in education and research.

Shubnikov Institute of Crystallography

European XFEL and the Shubnikov Institute of Crystallography of the Russian Academy of Sciences (IC RAS) cooperate in the growth and handling of crystals for optical elements as well as in organizing European XFEL schools for young scientists in Moscow.

STFC

The Science and Technology Facilities Council (STFC) in Swindon, UK, develops the Large Pixel Detector (LPD) for the European XFEL as well as hardware elements for the readout and data acquisition architecture.

University College London

The clock and control hardware for the European XFEL detectors is being developed at University College London (UCL) in the UK.

University of Hamburg

European XFEL and the School of Mathematics, Informatics and Natural Sciences (MIN) at the University of Hamburg, Germany, cooperate in research and teaching. The main focus is on exchanging know-how, implementing joint research projects, providing mutual access to experimental facilities, and promoting undergraduates, Ph.D. students, and young scientists. A contract was signed on 15 August 2011.

Figure 4 Representatives of European XFEL and the MIN School at the University of Hamburg with the signed cooperation agreement
Left to right Serguei Molodtsov, European XFEL; Heinrich Graener, MIN; Massimo Altarelli and Karl Witte, European XFEL; Daniela Pfannkuche, MIN; and Thomas Tschentscher, European XFEL

Uppsala University
European XFEL and Uppsala University in Sweden cooperate in the field of X-ray science with a focus on structural biology. Professor Janos Hajdu acts as a senior advisor to the scientific directors of European XFEL and contributes his expertise to the realization of measuring stations and experiments. An agreement was signed on 15 October 2010.

Participation in EU programmes

BioStruct-X
BioStruct-X is a consortium of 19 institutions from 11 European Union (EU) member and associated states. Within a broader research programme, European XFEL scientists work with colleagues from leading international research centres to improve the structure determination of biomolecules. The EU project was started in 2011.

CRISP
The Cluster of Research Infrastructures for Synergies in Physics (CRISP) is an EU research network of 11 European research infrastructures currently being planned or under construction. CRISP receives funding from the EU Seventh Framework Programme (FP7/2007–2013) and was launched on 17 October 2011. The network focuses on four key areas of physics: accelerator technology, physics instrumentation and experiments, detectors and data acquisition technologies, and IT and data management systems.

Memberships in research cooperations

Development and Use of Accelerator-Driven Photon Sources
European XFEL participates in the German–Russian bilateral funding programme "Development and Use of Accelerator-Driven Photon Sources". Several projects have been approved.

EIROforum
EIROforum is a collaboration between eight European intergovernmental research organizations (EIROs): EMBL, ESRF, European Fusion Development Agreement—Joint European Torus (EFDA-JET), European Organization for Nuclear Research (CERN), European Southern Observatory (ESO), European Space Agency (ESA), European XFEL, and Institut Laue-Langevin (ILL). The mission of EIROforum is to combine resources, facilities, and expertise to support European science in reaching its full potential. EIROforum also publishes a free journal, *Science in School*, which promotes inspiring science teaching.

Hard X-ray FEL collaboration (formerly "FEL three-site meeting")
The LCLS, the Japanese SPring-8 Compact SASE Source (SCSS), and the Hamburg FEL projects (FLASH at DESY and European XFEL) collaborate, share project information, and identify topics of common interest in a meeting series.

Physics on Accelerators and Reactors of Western Europe

In November 2010, European XFEL joined the “Physics on Accelerators and Reactors of Western Europe” programme of the Russian Ministry of Education and Science. The programme funds research stays of Russian scientists at large leading European research facilities. ■

PRESS AND PUBLIC RELATIONS

To ensure long-term acceptance of a new research facility locally, nationally, and internationally, it is essential to provide open, honest, and comprehensive information to the public on a regular basis. Since early 2008, a dedicated Press and Public Relations (PR) group serves as the interface between the public and European XFEL. The team fosters contact with local, national, and international media, publishes the European XFEL web portal and other information materials for various target groups, and presents the European XFEL at selected events. During civil construction (2009–2014), major emphasis is also being placed on communication with local residents, as the X-ray laser facility is located in a predominantly residential area.

Neighbourhood work

The neighbourhood office is open to local residents at any time. The PR group makes a special point of establishing contact with the residents living near the three sites of the European XFEL and along the tunnel route. The group informs these long-term neighbours about upcoming construction work through specially designed flyers and brochures, as well as through the Internet, email, phone calls, and even personal visits.

The 2 km long accelerator tunnel, which runs under a largely residential area, was constructed in 2011. Neighbourhood work therefore took up a large portion of PR capacity. During 10 months of the year, people living above and near the tunnel route reported disturbances by vibrations and noise. These disturbances had several causes: the tunnel boring machine (TBM); its supply train, which drove back and forth regularly between the Schenefeld construction site and the location of the TBM; and, later, the vehicles used for the installation of the tunnel floor. In addition, residents near the tunnel route expressed concern about a subsidence that appeared to be caused by the tunnel construction in the garden of a private house above the tunnel.

Figure 1 In one of the two information points on tunnel construction, local residents learn more about the status of civil construction.

Figure 2 At the DESY Open Day and Hamburg Science Night, European XFEL opens the undulator test hall for visitors. For twelve hours, visitors are offered a rich programme. The first original undulators and the test stand, a model of the tunnel boring machine, time-lapse movies of the evolution of the construction sites, a trail with experiments on lasers, magnetism, and superconductivity, and the support from European XFEL staff and civil engineers make for a fascinating visit.

The neighbourhood office met the overall situation with several measures. A short film about the tunnel construction was created and distributed to all neighbours in person. A tunnel construction site was made available on the Internet. In two places along the tunnel route, an information point on tunnel construction was set up for four weeks each (Figure 1). About 300 neighbours came to a special tunnel construction site day. There was a public evening lecture. With the cooperation of Deutsches Elektronen-Synchrotron (DESY), a website was published that provided current information about the subsidence. Overall, the PR team had around 800 individual contacts to local residents, mainly in the form of home visits and telephone calls.

Accomplishments

In 2011, the PR team accomplished the following major objectives:

- Produced and published the first annual report, the *European XFEL Annual Report 2010*
- Expanded the English- and German-language web portal (www.xfel.eu), adding information on in-kind contributions, a list of publications, and 190 new items for the media database
- Published twice as many news items as in 2010
- Participated in social media like YouTube (with 34 films), Facebook, and Twitter
- Started a PR collaboration with the Polish shareholder
- Represented European XFEL at the DESY Open Day and Hamburg Science Night with an exhibition in the undulator test hall
- Took part in the PR activities of EIROforum ■

TECHNICAL COORDINATION AND SAFETY

The construction, installation, and commissioning of the European XFEL, as well as its later operation, require system integration, project scheduling, technical support, facility management, and safety services. These services are provided by the Technical Coordination (TC) group for the teams that build the components, the scientists who set up the instruments, and the future users of the facility.

One group, many services

The TC group delivers the following services:

- Supporting the planning, integration, and installation work of the European XFEL construction project through a TC team staffed jointly by European XFEL and Deutsches Elektronen-Synchrotron (DESY)
- Setting up mechanical, electrical, and electronics workshops, as well as providing technicians and engineers for the work packages involved in the photon beamlines and the experiment hall
- Planning and supporting the buildup of temporary technical facilities (for example, labs, clean rooms, workshops, and storage spaces) before the Schenefeld premises become available
- Planning the technical infrastructure for the office building in Schenefeld as well as maintaining buildings and technical infrastructure
- Providing legally required general safety supervision for European XFEL and technical emergency services during operation of the facility

System integration and project scheduling

TC ensures that all project stakeholders have a common understanding of how budgets and schedules affect them:

- What has to be done
- Who has to do it
- When it has to be done

TC ensures that all project stakeholders act on this knowledge and provides them with the support to achieve these goals. TC is the primary systems integrator for the construction of the European XFEL. TC effects and steers the overall integration of deliverables and pre-integrated subsystems into a fully functional facility.

Specifically, TC does the following:

- Ensures technical coherence of the deliverables of the individual work packages
- Identifies and follows up on common issues between different work packages, and helps resolve the question of “who does what”
- Resolves technical conflicts by arbitrating between work packages
- Provides direct support to the work packages, where needed

In 2011, TC restructured project scheduling as a tool to keep track of the critical path of the project. The key to solving this problem was the establishment of the so-called project integration time (PIT) schedule. The structure of project integration planning is shown in Figure 1. TC sets up and maintains the PIT schedule, which comprises the ready dates from individual work packages or from pre-integration plans, and provides global milestones that can be tracked in the global project schedule.

TC is a global function in the project and covers the activities of European XFEL as well as those of the Accelerator Consortium led by DESY. For this reason, the TC team is staffed jointly by European XFEL and DESY.

Technical support

For the preparation of the photon beamline systems for the European XFEL, the technical and scientific groups need ready access to mechanical, electrical, and electronics workshops, as well as engineering support. For this purpose, a technical support team is being built up consisting of engineers and technicians. The team will serve as a central pool of know-how and will satisfy the needs foreseen during the peak installation phases. Hiring

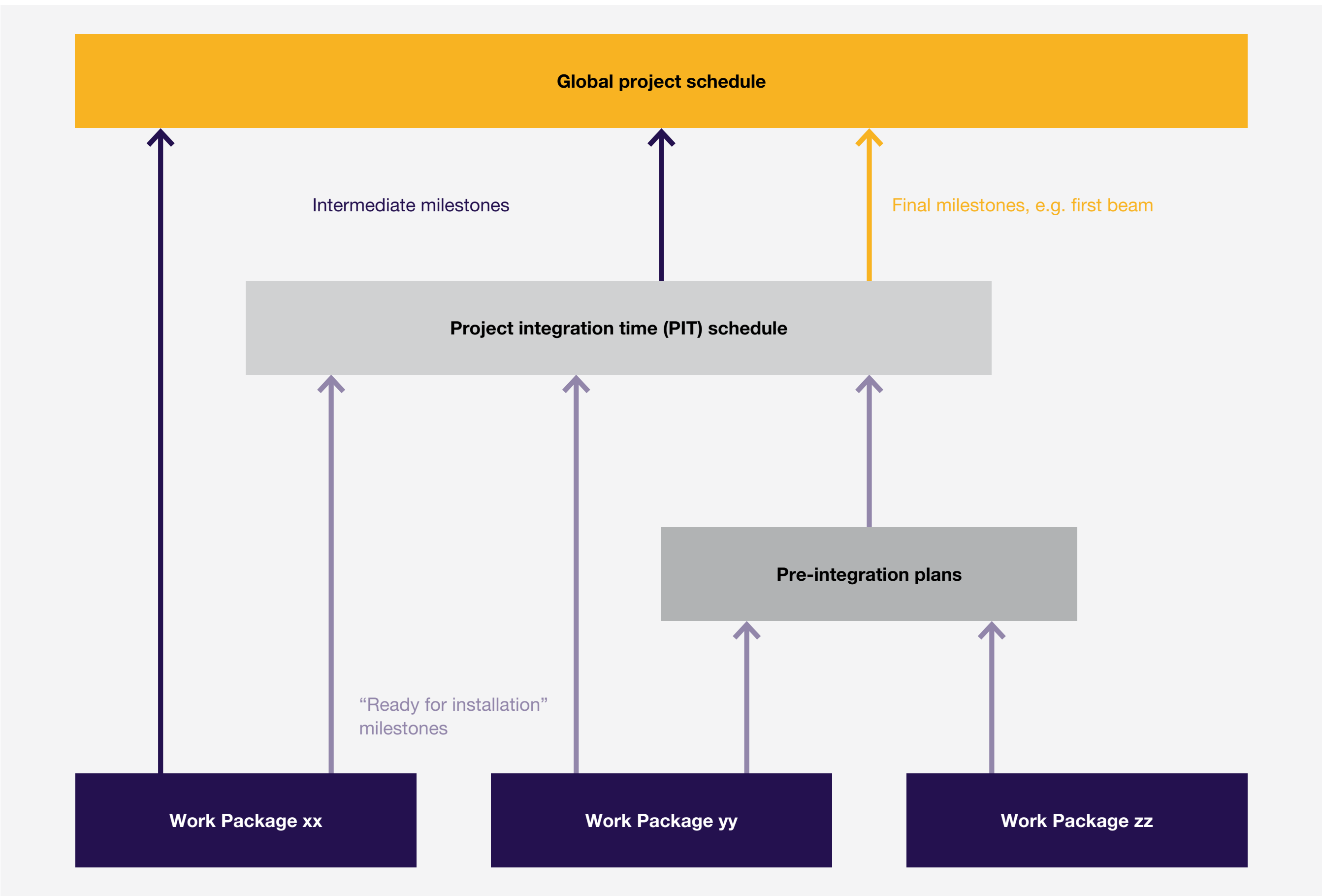


Figure 1 Structure of project integration planning

for the technical support team has begun. Two technicians have already started work. Initially, they will be in DESY workshops to acquire the skills that will be needed during the installation of the photon beamlines and scientific instruments in the experiment hall in Schenefeld.

To provide the technical and scientific groups of European XFEL with quick and easy access to both mechanical and electrical workshop services, framework contracts are being set up.

Temporary labs and storage

To prepare the photon beamline systems, temporary laboratory, assembly, and storage space is urgently needed on the DESY campus or in the immediate vicinity, as there will be no facilities available on the Schenefeld campus before 2015. It is essential that the temporary lab space for the different activities be located as close together as possible to share common infrastructures.

In 2011, it was determined that the DESY hall HERA-S (formerly home of the ZEUS experiment) was well suited for this purpose. However, the hall required extensive cleanup, including removal of more than 2 000 t of iron, copper, and steel that remained from the decommissioned ZEUS detector. After successful negotiations between European XFEL and DESY concerning the use of the hall, cleanup started in October 2011. Its progress can be seen in Figure 2. The HERA-S hall will be fully at the disposal of European XFEL in the second quarter of 2012.

Figure 2 HERA-S hall in a state of partial cleanup

Facility management

In 2011, as part of the effort to plan the technical infrastructure for the laboratories and the office building on the Schenefeld site, the position of facility manager was defined and assigned to an engineer with the appropriate qualifications. This engineer will build up the facility management team. The specific tasks of the team are to plan the precision measurement rooms, the laboratories, and the general technical infrastructure of the European XFEL office building that will be located on top of the experiment hall in Schenefeld. The facility manager will also be responsible for the precision air conditioning system for the undulator sections. In addition, the team currently handles the day-to-day business of the temporary accommodation in the present office space of European XFEL at Albert-Einstein-Ring 19.

Occupational health and safety

In 2011, European XFEL took further steps towards a well-functioning occupational health and safety organization for the construction and the operational phase. The occupational safety committee had its regular meetings and, in November, an experienced occupational safety expert (*Fachkraft für Arbeitssicherheit*) was hired. This specialist will advise and support the European XFEL Management Board and staff in all matters of occupational health and safety.

Tentative safety guidelines—including an overview of the company's safety organization—are currently being developed. The emergency procedures at the office building at Albert-Einstein-Ring 19 have already been reviewed. Volunteers are being trained as first aiders and helpers in the event of an evacuation. Next steps will be the review of risk assessments of all working areas and all activities, both present and planned throughout 2012.

Beginning in 2012, regular general safety training for newcomers and guests will be offered in German and English. An English-language version of the occupational health and safety guidelines has been drafted. This guide provides a code of conduct and explains the German safety laws and rules most relevant for the company. In addition, occupational safety will be more visible thanks to a regular update of all relevant safety issues on the company intranet and on the new safety bulletin boards.

In 2012, first steps will be taken to set up a radiation protection organization for ongoing research activities at present laboratories and for eventual activities at the future European XFEL headquarters in Schenefeld. These steps will be taken in close collaboration with DESY.

Group members
Marco Schrage, Carola Schulz, Sigrid Kozielski, Sabine Cunis, Tobias Haas (group leader), and Maik Neumann

SERVICES

An advanced scientific facility such as the European XFEL requires a highly professional administrative infrastructure. In 2011, extensive international recruiting was accompanied by intensified relocation, training, and compensation efforts. The project not only creates jobs but stimulates the economy: in 2011, 90% of the project budget went to capital investments.

Recruiting staff

In 2011, recruitment of personnel continued at full speed. As of December, 119 employees worked for European XFEL, an increase of 61% compared to 2010. In 2011, the Human Resources group processed 1 009 applications for 47 advertised positions. In 2012, European XFEL plans to fill another 50. All open positions are advertised internationally.

Of all European XFEL employees, 46% are scientific, 25% engineering and technical, and 29% administrative staff (Figure 1). While hiring for the administrative positions is almost complete, the number of scientific, engineering, and technical employees continues to grow rapidly.

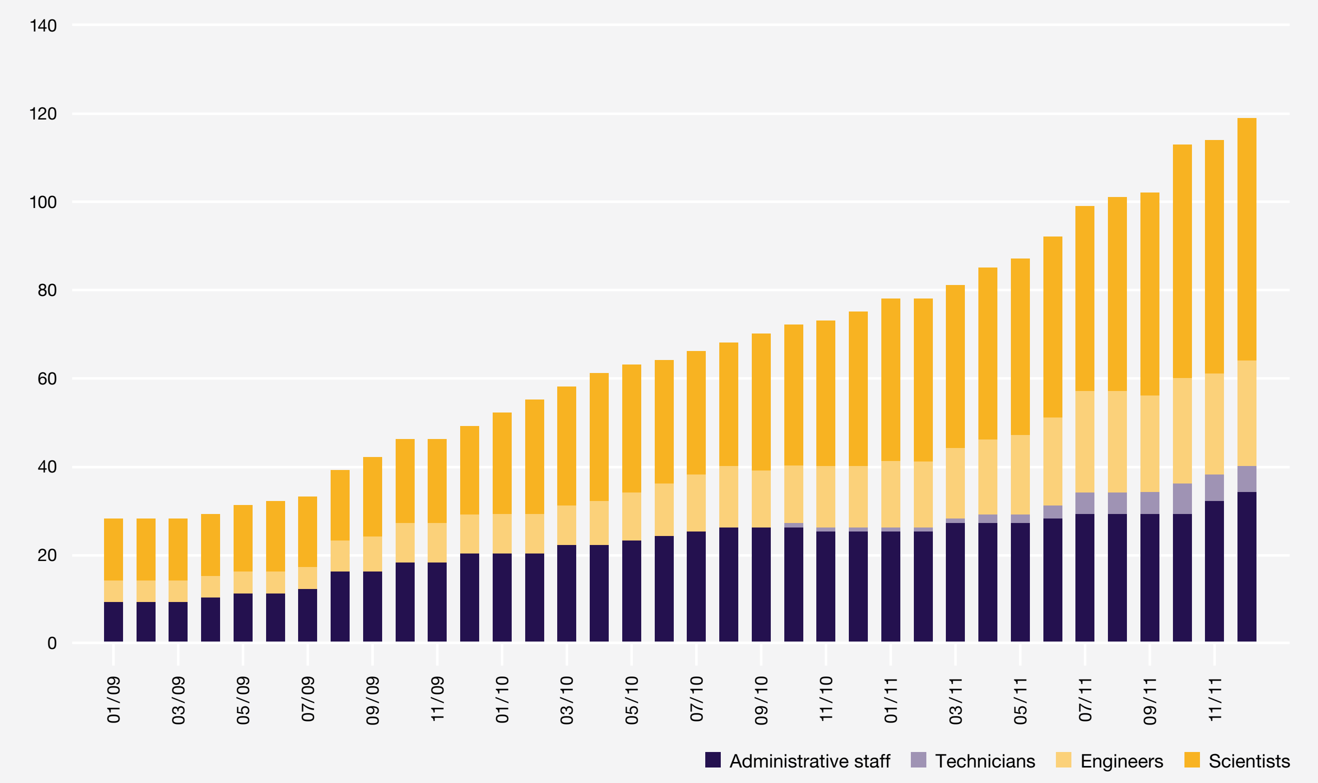


Figure 1 Overall staff growth 2009–2011

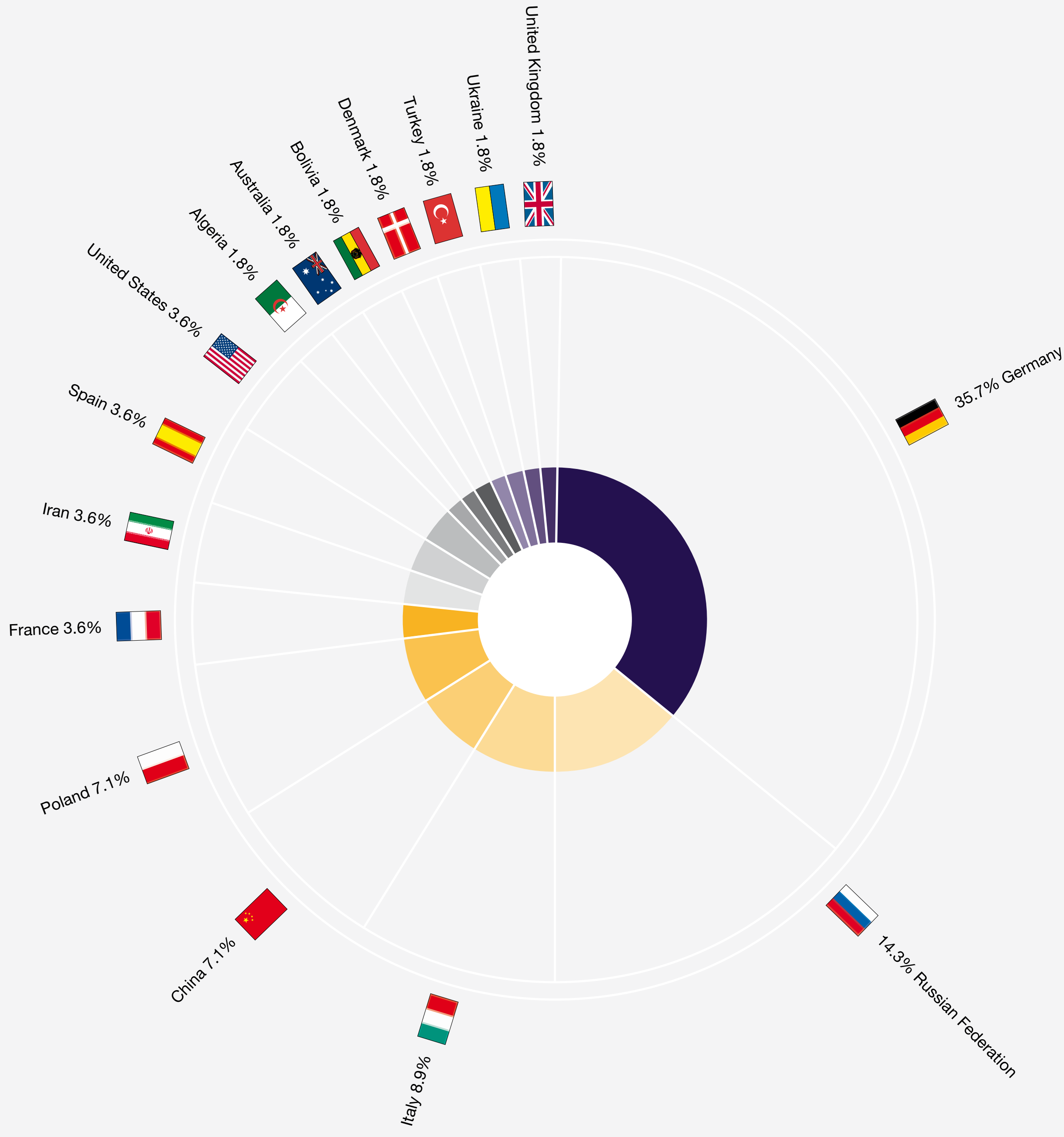


Figure 2 Nationalities of scientific staff

European XFEL comprises employees from 19 countries around the world. The percentage of scientists from outside of Germany grew from 62% in 2010 to 64% in 2011 (Figure 2).

The percentage of total (scientific and non-scientific) staff from outside of Germany remained nearly constant at 42% (Figure 3).

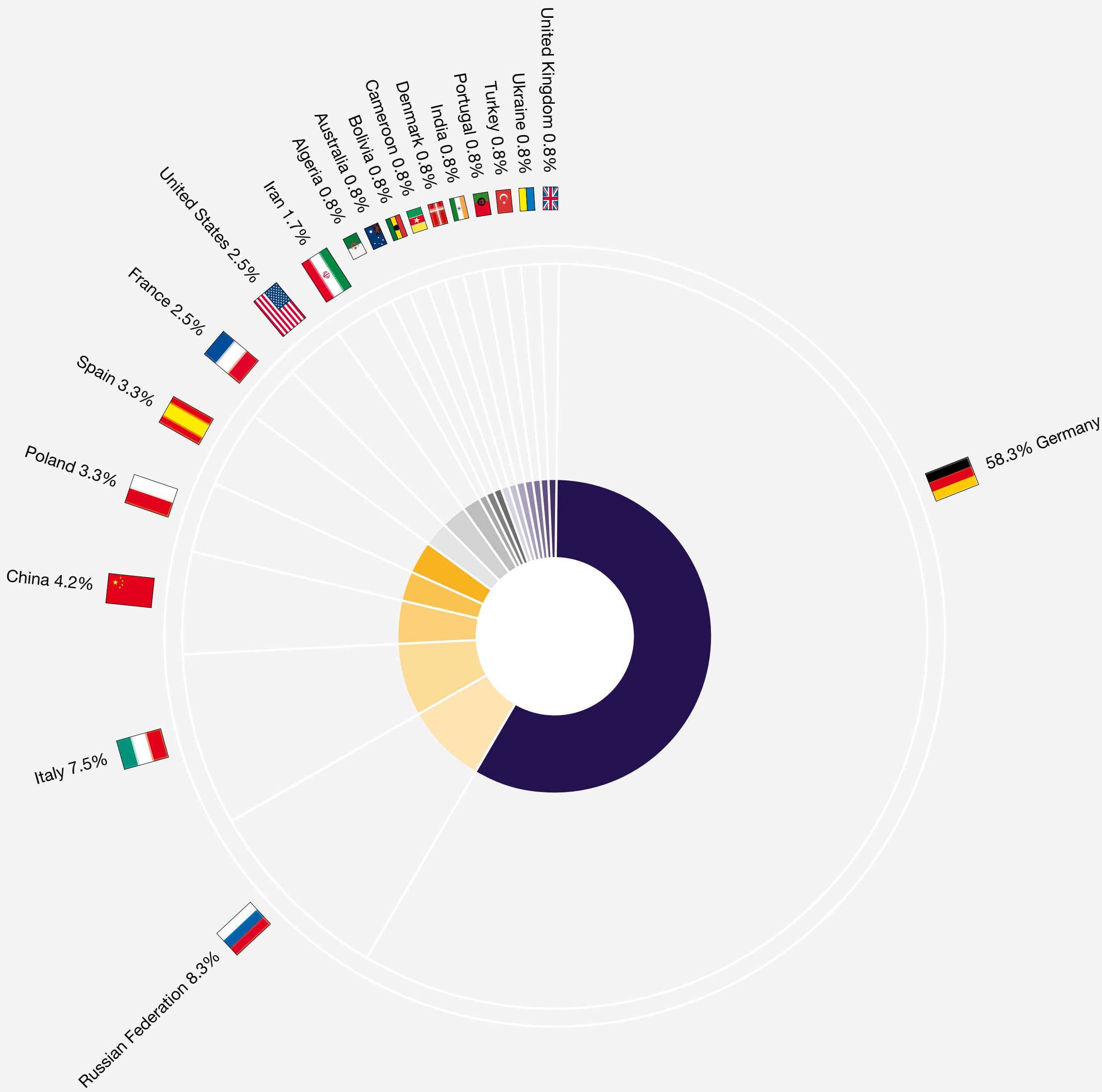


Figure 3 Nationalities of all (scientific and non-scientific) staff

The increasing number of international recruitments was accompanied by intensified relocation efforts. Not only does the company provide relocation services to new employees from abroad, it actively supports their families, especially with finding appropriate schooling and child day care. In 2011, we helped new employees and families from Algeria, Austria, Canada, France, Italy, Portugal, Spain, and the UK.

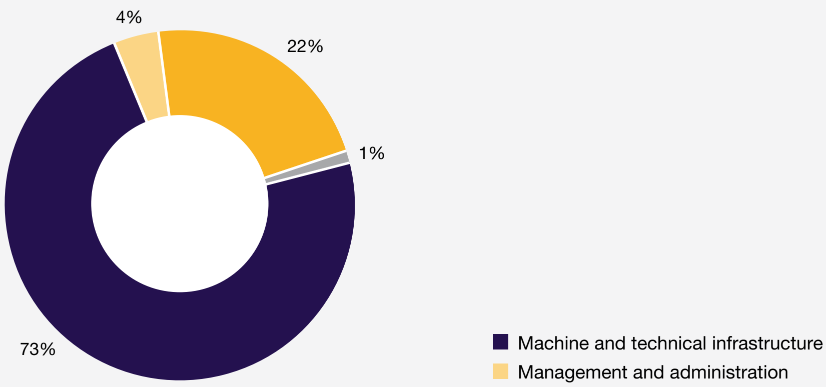


Figure 4 Payments by major activity

The company pursues an equal opportunity policy. The share of female employees at European XFEL is 28%.

Developing staff

At the beginning of 2011, an obligatory annual employee interview was introduced. During the interview, employees and their supervisors define consensual objectives for the current year and make suggestions for improving employee performance. In addition, employees provide feedback to supervisors. As of 2012, supervisors will use the interview to evaluate how well employees have achieved the objectives agreed upon the previous year. The evaluation will then determine annual incentive pay, as defined in the European XFEL Staff Rules.

In 2011, training activities were intensified. Key activities were the introduction of in-house leadership training, which is compulsory for all supervisors, and the implementation of training through EIROforum (for example, for project management and scientific presentations).

Investing in the future

For the business year 2011, the total European XFEL payment budget amounted to 129.7 million euro (M€). With an annual payment budget of 95.3 M€, machine and technical infrastructure were by far the largest activity of the project budget. This activity included civil construction with 80.9 M€, of which 77 M€ was related to underground construction. Beamlines and experiments were the second-largest activity of the project, amounting to 28.2 M€, of which 78% was related to capital investment. In-house research (R&D for instruments) covered 0.9 M€. Only 4%, or 5.3 M€, of the total annual budget for 2011 was related to management and administration.

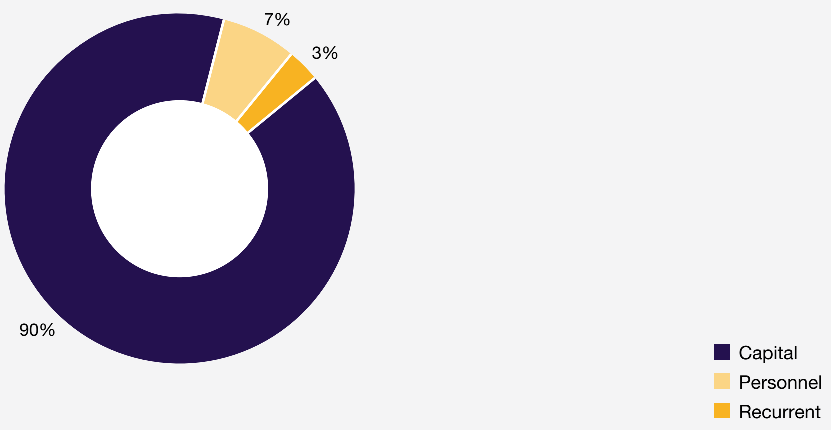


Figure 5 Payments by budget items

Of the total European XFEL project budget for 2011, 90% was spent on capital investments (116.5 M€) and only 7% for personnel expenses (8.6 M€). The remaining 3% was related to recurrent costs (4.5 M€).

According to studies by the Institute for Allocation and Competition at the University of Hamburg, strong economic benefits are likely to result from the investment activities of European XFEL. Not only does the project create new jobs and secure existing ones, it stimulates the innovation of its suppliers.

For the budget year 2012, a total annual payment budget of 140.2 M€ was approved, out of which 122.1 M€ applies to capital investments. ■

Staff and guests of the European XFEL GmbH (December 2011)

Agapov, Ilya
Altarelli, Massimo
Ament, Kurt
Aquila, Andrew
Bakthiarzadeh, Sadegh
Bartmann, Alexander
Batindek Embok, Camille
Beckmann, Andreas
Berninger, André
Böhringer, Karin
Boukhelef, Djelloul
Bukreeva, Inna
Bressler, Christian
Buck, Jens
Coppola, Nicola
Cuna Rodriguez, Enrique
Cunis, Sabine
Dastjani Farahani, Shafagh
Deron, Georg
Desai, Abhishek
Dommach, Martin
Ebeling, Bernd
Eder, Catherine Ann
Englisch, Uwe
Esenov, Sergey
Fernandes, Bruno
Fischer, Christopher
Flammer, Meike
Folkerts, Petra
Freijo Martín, Idoia
Freund, Wolfgang
Gaida, Manfred
Galler, Andreas
Gaudin, Jérôme
Gawelda, Wojciech
Geloni, Gianluca
Gembalies, Imke
Geßler, Patrick
Giewekemeyer, Klaus
Grünert, Jan
Guhlmann, Florian
Haas, Tobias
Hagitte, Martin
Hallmann, Jörg
Heeßel, Gabi
Heisen, Burkhard
Izquierdo, Manuel
Kabachnik, Nikolay
Karabekyan, Suren
Kellert, Martin
Knaack, Manfred
Knoll, Martin
Koch, Andreas
Kohlstrunk, Nicole
Kosemund, Michael
Kozielski, Sigrid
Kozlova, Iryna
Krupin, Oleg
Kunz, Marc
Kuster, Markus
Laub, Malte
Lederer, Maximilian
Li, Bin
Li, Yuhui
Liebram, Axel
Linnemann, Jens
Madsen, Anders
Mancuso, Adrian
Mazza, Tommaso
Mendez, Cruz
Mergen, Julia
Meyer, Michael
Molodtsov, Serguei
Mulá Mathews, Gabriella
Nawrath, Günther
Nemitz, Olaf
Neumann, Maik
Osterland, Christiane
Özkan, Cigdem
Pereira Bahia, Liliane
Pergament, Mikhail
Pflüger, Joachim
Poljancewicz, Bartosz
Poppe, Frank
Prat, Serge
Priemer, Thomas
Raciniewski, Magdalena
Röhling, Maike
Rüscher, Jan Christoph
Rychev, Mikhail
Samoylova, Liubov
Sauermann, Wolf-Ulrich
Schrage, Marco
Schulz, Carola
Schulz, Joachim
Schwarz, Andreas S.
Schimanke, Thimo
Shie, Halimah
Sinn, Harald
Smolyakov, Nikolay
Suhr, Stephanie
Sztuk-Dambietz, Jolanta
Szuba, Janusz
Tomin, Sergey
Trapp, Antje
Tschentscher, Thomas
Tscheu, Wolfgang
Turcato, Monica
Uetrecht, Charlotte
van Hees, Brunhilde
Villanueva Guerrero, José
Wang, Xuetao
Weger, Kerstin
Witte, Karl
Wolfarth, Svenja
Wrona, Krzysztof
Yang, Fan
Youngman, Christopher

Figure 6 Ninety-three European XFEL staff members and guests at the entrance of the accelerator tunnel (March 2012)

SHAREHOLDERS

The European XFEL is organized as a non-profit company with limited liability (GmbH) under German law that has international shareholders. The shareholders are designated by the governments of the international partners who commit themselves in an intergovernmental convention to support the construction and operation of the European XFEL.

Shareholders of the European XFEL GmbH (December 2011)	
Denmark	DASTI (Danish Agency for Science, Technology and Innovation)
Germany	DESY (Deutsches Elektronen-Synchrotron)
Hungary	NIH (National Innovation Office)
Poland	NCBJ (National Centre for Nuclear Research)
Russia	RUSNANO (Russian Corporation of Nanotechnologies)
Slovak Republic	Slovak Republic, represented by the Ministry of Education, Science, Research and Sport
Sweden	VR (Swedish Research Council)
Switzerland	Swiss Confederation, represented by the State Secretariat for Education and Research

Likely future shareholders of the European XFEL GmbH	
France	CEA (Alternative Energies and Atomic Energy Commission), CNRS (National Centre for Scientific Research)
Italy	Republic of Italy, represented by the Ministry of Education, University and Research
Spain	Kingdom of Spain, represented by the Ministry of Economic Affairs and Competitiveness

ORGANS AND COMMITTEES

The Council of the European X-Ray Free-Electron Laser Facility GmbH (European XFEL GmbH) is the supreme organ of the company. It functions as the shareholders' assembly and decides on important issues of company policy.

The European XFEL Management Board is composed of the managing directors (*Geschäftsführer*) in the sense of the German law on companies with limited liability (GmbHG) and three scientific directors.

Advisory committees support the European XFEL GmbH in various matters (Administrative and Finance Committee, Machine Advisory Committee, Scientific Advisory Committee, In-kind Review Committee, Detector Advisory Committee, and Advisory Review Teams for scientific instruments as well as for X-ray optics and beam transport systems).

European XFEL Council	
Chairman	Robert K. Feidenhans'l (University of Copenhagen, Denmark)
Vice chairman	Pavol Sovák (P.J. Šafárik University, Košice, Slovak Republic)
Delegates	
Denmark	Anders Ødegaard / Anders Kjær (DASTI, Copenhagen) and Martin Meedom Nielsen (DTU, Roskilde)
Germany	Helmut Dosch (DESY, Hamburg) and Beatrix Vierkorn-Rudolph (BMBF, Bonn)
Hungary	Dénes Lajos Nagy (KFKI, Budapest)
Poland	Grzegorz Wrochna (NCBJ, Otwock)
Russia	Mikhail Kovalchuk (NRC KI, Moscow) and Andrey Svinarenko (RUSNANO, Moscow)
Slovak Republic	Karel Saksl (Institute of Materials Research, SAS, Košice)
Sweden	Lars Börjesson (Swedish Research Council, Stockholm)
Switzerland	Bruno Moor (State Secretariat for Education and Research, Bern)
Secretary	
	Stephanie Suhr (European XFEL, Hamburg)

European XFEL GmbH Management Board	
Chairman	Massimo Altarelli
Administrative Director	Karl Witte (through 2011) Claudia Burger (as of 2012)
Scientific Director	Serguei Molodtsov
Scientific Director	Andreas S. Schwarz
Scientific Director	Thomas Tschentscher

Administrative and Finance Committee (AFC)	
Chairman	Andreas Werthmueller (State Secretariat for Education and Research, Bern, Switzerland)
Delegates	
Denmark	Anders Ødegaard / Anders Kjær (DASTI, Copenhagen)
Germany	Sebastian Jester (BMBF, Bonn) and Christian Scherf (DESY, Hamburg)
Hungary	Barbara Vizkelety (NIH, Budapest)
Poland	Zbigniew Golebiewski (NCBJ, Otwock)
Russia	Alexey Raykevich (RUSNANO, Moscow) and Valeriy Nosik (NRC KI, Moscow)
Slovak Republic	Pavol Sovák (P.J. Šafárik University, Košice)
Sweden	Inger Andersson (Swedish University of Agricultural Sciences, Uppsala) and Elin Swedenborg (Swedish Research Council, Stockholm)
Switzerland	Peter Allenspach (PSI, Villigen)
Secretary	
	Meike Flammer (European XFEL, Hamburg)

Machine Advisory Committee (MAC)	
Chairman	Mikael Eriksson (MAX-lab, Lund, Sweden)
Members	
	Hans-Heinrich Braun (PSI, Villigen, Switzerland)
	Paul Emma (LCLS SLAC, California, USA)
	Massimo Ferrario (INFN, Frascati, Italy)
	Jacek Krzywinski (SLAC, California, USA)
	Gennady Kulipanov (BINP, Novosibirsk, Russia)
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	Horst Schulte-Schrepping (DESY, Hamburg, Germany)
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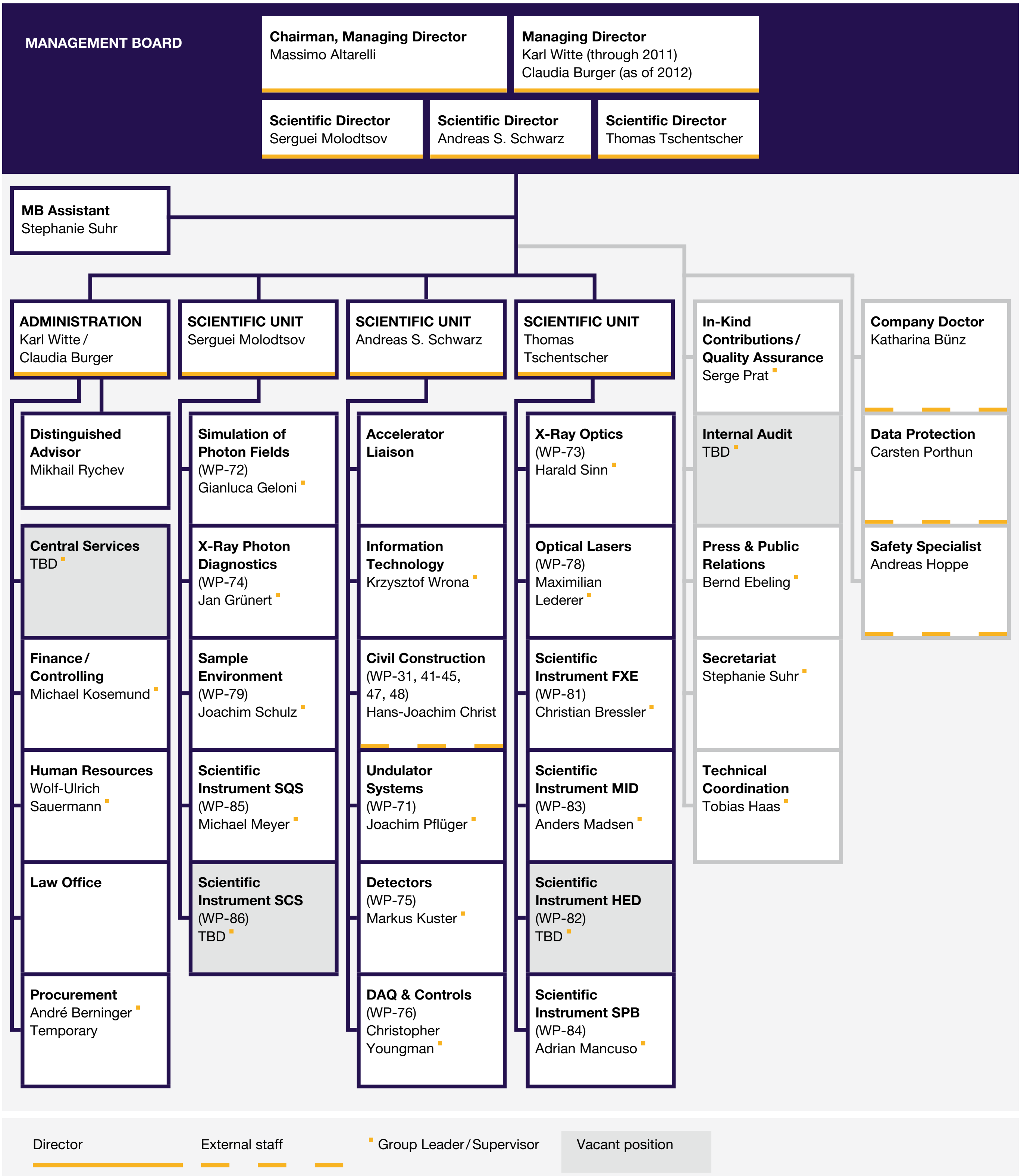

European X-Ray Free-Electron Laser Facility GmbH (December 2011)

08 SCIENTIFIC RECORD

Although the European XFEL is still under construction, the scientific record is impressive. In 2011, the company hosted the 5th Users' Meeting and over a dozen international seminars. Staff members published over 30 scientific articles and technical reports, and spoke at numerous conferences.

EUROPEAN XFEL USERS' MEETING

26–28 January 2011
Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

The European XFEL Users' Meeting is an annual opportunity to strengthen the interaction between the European XFEL project and the scientific user community. As in previous years, the fifth such meeting saw an increase in the number of potential users of the facility. Most of the record number of more than 320 participants from 24 countries—including almost all European XFEL partner countries, as well as Belarus, Belgium, China, the Czech Republic, Finland, Ireland, the Netherlands, the UK, and the USA—travelled to Hamburg for the meeting. It seemed that the excitement about research possibilities at the European XFEL actually increased.

The 5th European XFEL Users' Meeting focused on the following:

- Progress and current status of the European XFEL
- Selected science applications
- Results of technical and scientific workshops in 2010
- Current developments in the field of X-ray free-electron laser (FEL) facilities
- Job opportunities at European XFEL

Figure 1 Participants of the 5th European XFEL Users' Meeting (January 2011)

2ND INTERNATIONAL SCHOOL FOR YOUNG SCIENTISTS

16 November 2011
Institute of Crystallography RAS, NRC Kurchatov Institute, Moscow, Russia

At the initiative of the Russian science community, the 2nd International School for Young Scientists was held in Moscow in November 2011. The aim of the school is to educate young scientists in state-of-the-art research in photon science using FEL radiation. The second international school provided presentations on European XFEL facility techniques, as well as scientific talks on instruments and their future research challenges. The lectures were delivered by more than 10 top scientists from European XFEL.

WORKSHOP

22–23 September 2011
CFEL/DESY/European XFEL workshop on temporally and spatially resolved dynamical phenomena
Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

The purpose of the workshop on temporally and spatially resolved dynamical phenomena was to bring together experts working on the dynamics of complex systems at the forefront of molecular science, bioscience, and nanoscience in order to identify key problems that, if solved, would lead to dramatic breakthroughs. The main task of the experts participating in the workshop was to freely speculate and provide ideas of what they believed would be the key issues in their fields in the next 10 years. The conclusions of the workshop were collected in a report that provides guidance in identifying the key problems to be addressed by X-ray FEL experiments and in preparing beamtime proposals.

SEMINARS

13 January 2011
High speed liquid microjet targets in EUV/XPS experiments
Manfred Faubel, Max-Planck-Institut für Dynamik und Selbstorganisation, Göttingen, Germany

20 January 2011
A sub-picosecond hard X-ray streak camera using single-photon counting
Jorgen Larsson, Atomic Physics Division, Lund University, Lund, Sweden

3 March 2011
Horus—A detector simulation tool
Julian Becker, Hamburg Synchrotron Radiation Laboratory (HASYLAB) / Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

17 March 2011
What lasers can do for X-ray FELs
Franz X. Kärtner, Center for Free-Electron Laser Science (CFEL), Hamburg, Germany, and Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

21 March 2011
Partially coherent wavefront propagation calculations
Oleg Chubar, Photon Sciences Directorate, Brookhaven National Laboratory (BNL), Upton, NY, USA

25 March 2011
An approach for few femtosecond timing of fourth generation X-ray lightsources and single shot electron bunch diagnostics
Michael Gensch, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany

11 April 2011
Picosecond X-ray emission spectroscopy at MHz repetition rates
Pieter Glatzel, European Synchrotron Radiation Facility (ESRF), Grenoble, France

19 May 2011
Phase resolved attosecond photoionization
Yann Mairesse, Center for Intense Lasers and Applications (CELIA), Université Bordeaux I, France

1 July 2011
High repetition rate ultrafast time-resolved X-ray absorption spectroscopy
Christopher J. Milne, École Polytechnique Fédérale de Lausanne (EPFL), Swiss Light Source, Paul Scherrer Institut (PSI), Villigen, Switzerland

4 November 2011
Refractive X-ray Optics for Experiments with Coherent Radiation
Christian Schroer, Institut für Strukturphysik, TU Dresden, Dresden, Germany

9 November 2011
The bio-imaging and diffraction beamline P11 at PETRA III
Alke Meents, Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

10 November 2011
In-situ X-ray reflectometry: Possibilities and perspectives
Igor V. Kozhevnikov, Shubnikov Institute of Crystallography, Moscow, Russia

18 November 2011
Probing non-equilibrium first order phase transitions of long-range order with resonant and non-resonant sub-picosecond X-ray diffraction
Gerhard Ingold, Laboratory for Synchrotron Radiation, Paul Scherrer Institut (PSI), Villigen, Switzerland

28 November 2011
Single particle imaging experiments at the Linac Coherent Light Source (LCLS)
Andrew Martin, Center for Free-Electron Laser Science (CFEL), Hamburg, Germany
7 December 2011
X-ray Detector Development at Berkeley Lab
Peter Denes, Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA, USA

9 December 2011
Simulation of single-particle diffraction experiments—Requirements for hardware and software
Duane Loh, SLAC National Accelerator Laboratory, Stanford, CA, USA

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CONTRIBUTIONS TO CONFERENCE PROCEEDINGS

Damage on materials of interest for FEL optics
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The Local Control System of an Undulator Cell for the European XFEL
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