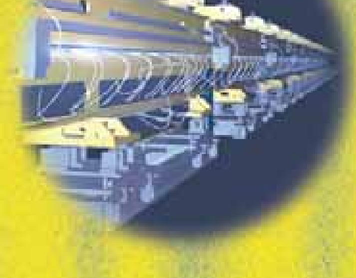
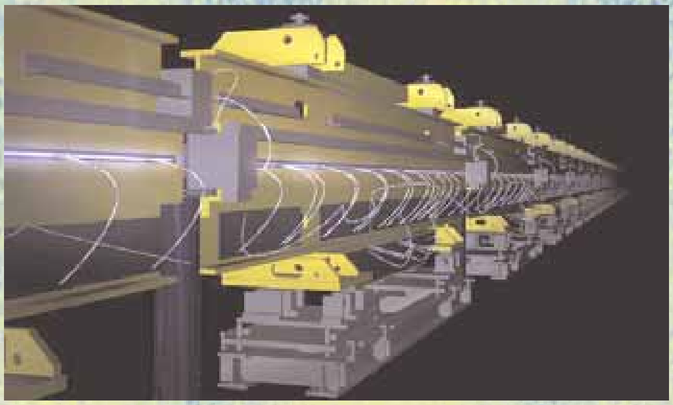
The Light of the Future

The European XFEL Facility

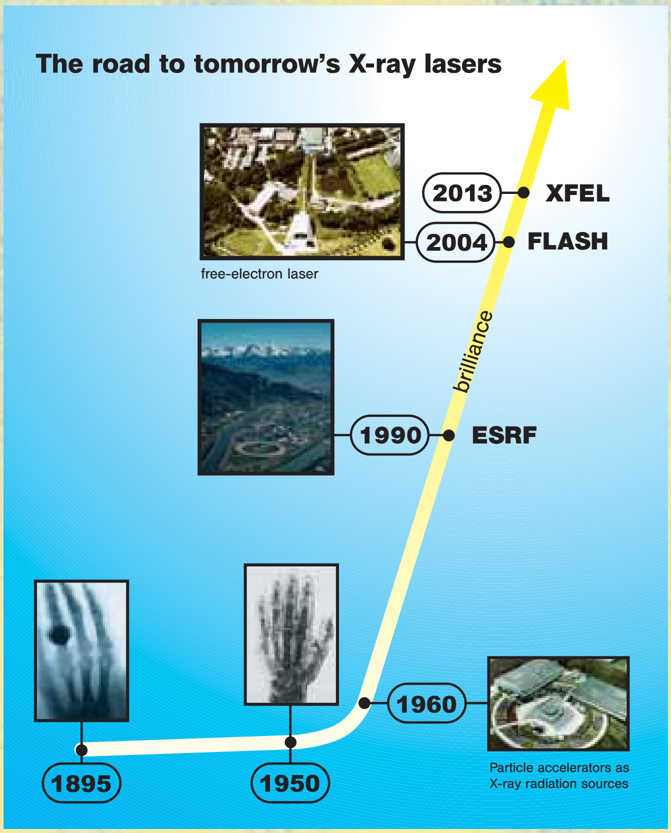


XFEL – The European X-Ray Free-Electron Laser

Scientists will soon be able to film events in the microcosm and find out how materials or biomolecules behave at the atomic level. Thanks to a unique source of light, researchers' visions will become a reality. The X-ray free-electron laser XFEL that is being planned at the DESY research center in cooperation with European partners will produce high-intensity ultra-short X-ray flashes with the properties of laser light. This new light source, which can only be described in terms of superlatives, will open up a whole range of new perspectives for the natural sciences. It could also offer very promising opportunities for industrial users.



The short-wavelength laser light is generated in a so-called undulator, an arrangement of many magnets.



Development of X-ray radiation sources

A Light Source of Superlatives

The new X-ray laser ventures into dimensions that have so far remained unexplored:

- At peak values, its brilliance is a billion times higher than that of the most modern X-ray light sources, and its average brilliance is 10 000 times higher.
- Its time resolution is several orders of magnitude better than that of the light sources available today: An X-ray flash is shorter than 100 femtoseconds (1 femtosecond is a thousand million millionth of a second). That is the amount of time it takes for chemical compounds to form and groups of molecules to change their position.
- The wavelength of its X-rays is so short that even atomic details become discernible. It can be varied between six nanometers and less than one-tenth of a nanometer (1 nanometer is a billionth of a meter).
- Its X-ray beam has the characteristics of laser light, i.e., it is coherent. This makes it possible to carry out holographic experiments at the atomic level.

A Multitude of Applications

The inconceivably brief and intense X-ray pulses will enable researchers to record what are essentially films with atomic resolution – for example, how a chemical reaction progresses, how biomolecules move, or how solids are formed. This will benefit a wide range of natural sciences – from physics and chemistry to materials science, geological research and the life sciences.

Leading-Edge Research in Europe

In February 2003, the German Federal Ministry of Education and Research gave the green light for the proposed X-ray laser, which is to be realized as a European project. This decision was based on a recommendation by the German Science Council (*Wissenschaftsrat*), which had assessed several large-scale facilities for basic research. The European X-ray laser facility XFEL will take up operation in 2013. It will enable leading-edge research in Europe and guarantee a major role for Germany as a location for research and industry.

Femtochemistry

In the field of femtochemistry, researchers work with minuscule fractions of a second as they trace the process of chemical reactions. "Femto" is the prefix for one thousand million millionth, and femtoseconds represent the time scale over which changes occur at the atomic level when two molecules are reacting. Ultra-fast lasers make it possible to take "snapshots" of the arrangements of molecules that form in the course of a chemical reaction, and when these images are viewed as a series, the result is a film of the reaction process. The experiments at the X-ray laser can create such films with an accuracy of detail and a time resolution that have never previously been attained. In these films, the reacting molecules are pictured with atomic resolution.

Structural Biology

With the help of the X-ray laser, biological structures can be decoded with atomic resolution. The X-ray laser flashes are so intense that they can be used to create images of single molecular complexes. Thanks to the ultra-short exposure times, researchers can also trace the movements of these molecular complexes. Such new insights, e.g., into the progress of infections at the molecular level, also form an essential basis for the development of new medicines.

Structure of the ribosome, the "protein factory" in living cells

Materials Research

The X-ray laser is enabling materials scientists to look forward to a dynamic future in which they will be able to answer questions such as: How is a solid body created? How do the rapid transformations between different states of matter take place? These are fundamental questions whose answers have a very practical value. For example, an understanding of the dynamic processes of friction and wear at the atomic level will provide the basic knowledge that scientists need to improve existing materials and develop new ones. The flashes of the X-ray laser are short and intense enough to record changes in materials on the smallest scales. This is also the basis for the development of tailor-made materials in the nano region, i.e., with dimensions of one billionth of a meter.

Pioneering Technology

The planned X-ray laser will include a superconducting electron accelerator that brings tightly bundled "bunches" of electrons to energies of 10 to 20 billion electronvolts. At that point, the electrons then race at almost the speed of light along a slalom course through a special arrangement of magnets called an "undulator." As they go, they emit X-ray radiation that amplifies itself during the flight. The results are brilliant: extremely short and intense X-ray flashes with laser properties. For such an X-ray laser to work, an electron beam of extremely high quality is required. The superconducting TESLA accelerator technology developed at DESY in international cooperation makes it possible to generate this kind of electron beam today.

Development Goal Achieved

The TESLA test facility at DESY in Hamburg impressively demonstrated that the innovative technology of the new X-ray free-electron laser works. From 1992 to 2004, an international team of researchers developed and tested the necessary technical components at this facility and thus laid the foundation for both the XFEL project and the proposed International Linear Collider (ILC) for particle physics. The superconducting TESLA accelerator technology forms the basis for both projects.

In one of the first experiments carried out at the free-electron laser of the test facility in 2002, an international team of scientists studied the interaction of matter (clusters of noble gas atoms) with intense X-ray radiation from a free-electron laser on extremely short time scales for the first time. The clusters are used as model substances in order to gain an understanding of basic processes that are relevant to future experiments with the X-ray laser. Such experiments will explore matter's behavior at extreme temperatures and densities, investigate technologically promising materials, or study medically important biomolecules.

The experimental hall of the 260-meter-long free-electron laser FLASH can be seen in the foreground, behind it is the DESY site.

FLASH – The Free-Electron Laser in Hamburg

FLASH is a free-electron laser at DESY that has been used for research with shortwave ultraviolet radiation since 2005. At 13.1 nanometers, the facility (formerly called VUV-FEL) generates the shortest wavelengths to date. After its final expansion, it will provide soft X-ray radiation with wavelengths down to six nanometers. Scientists use the radiation to carry out experiments in cluster physics, solid-state physics, surface physics, plasma research and molecular biology. Until 2009, FLASH will remain the worldwide only free-electron laser of its kind. As such, it provides important insights for the XFEL and other future free-electron laser projects. Both FLASH and the XFEL are based on the superconducting TESLA accelerator technology.

The DESY Research Center

The Deutsches Elektronen-Synchrotron (German Electron Synchrotron, DESY) was founded in Hamburg in 1959. It is a publicly funded national research center with two locations: Hamburg and Zeuthen (German state of Brandenburg). DESY is a member of the Helmholtz Association of National Research Centers.

DESY's task is to conduct basic research in the natural sciences with special emphasis on:
- the development, construction and operation of accelerator facilities
- the investigation of the fundamental properties of matter and forces (particle physics at HERA)
- the use of synchrotron radiation in the fields of surface physics, materials science, chemistry, molecular biology, geophysics and medicine (research with photons at HASYLAB)

DESY therefore conducts research across a broad interdisciplinary spectrum.

The DESY site in the western part of Hamburg is surrounded by the PETRA ring. Part of the 6.3-kilometer-long subterranean HERA facility also runs underneath Hamburg's Volkspark and residential and commercial areas of the city.

Budget and Financing
DESY Hamburg receives annual funding of 145 million Euro and DESY Zeuthen 15 million Euro. The German government finances 90% of the budget, with the remaining 10% provided by the City of Hamburg and the State of Brandenburg.

Employees
The total workforce at DESY (including doctoral students, trainees and young scientists) is made up as follows:
- in Hamburg:
  1400 employees, including 300 scientists
- in Zeuthen:
  200 employees, including 65 scientists

International Cooperation
The DESY accelerators are used for research purposes by 2750 scientists from 33 countries. Around 950 of these scientists work in the field of particle physics at the HERA facility. A further 1800 carry out research with photons at HASYLAB.

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XFEL: Milestones

The superconducting TESLA accelerator technology has been developed and tested in an international collaboration at a test facility at DESY in Hamburg. This technology forms the basis for the X-ray laser XFEL and for the proposed International Linear Collider (ILC) for particle physics. At this test facility the TESLA collaboration successfully attained key development targets under “original conditions”:

- In February 2000, scientists achieved a world first when they generated short-wavelength laser light in the ultraviolet range (80-180 nanometers) by using the pioneering SASE principle, on which the X-ray laser is based. The number of photons obtained at the free-electron laser in flashes of 50 femto-seconds duration is of the same order of magnitude as the number of photons obtained at modern synchrotron radiation facilities in 1 second.

- In December 2002, using the free-electron laser at the test facility, an international team of scientists studied the interaction of matter—small clusters of noble gas atoms—with intense X-ray radiation from a free-electron laser on extremely short time scales for the first time.

Electromagnetic fields accelerate the electrons in the superconducting resonators.

February 5, 2003
Fundamental decision of the German Federal Ministry of Education and Research: The X-ray laser laboratory is to be realized as a European project at DESY, and Germany will bear up to 60% of the total costs because of the advantage of location.

2004/2005
After its commissioning at the end of 2004, the free-electron laser FLASH (formerly called VUV-FEL) is being used for experiments at five measuring stations since August 2005. For the first time, the principle of single shot imaging of small particles and structures has been demonstrated on 30 nanometer length scales with pulses of about 20 femtoseconds duration.

Until the end of 2005
Denmark, France, Germany, Greece, Hungary, Italy, the People’s Republic of China, Poland, Russia, Spain, Sweden, Switzerland, and the United Kingdom sign a Memorandum of Understanding. This forms the basis for the establishment of an independent European XFEL research center, in which DESY will participate.

July 2006
After additional workshops and in-depth discussions in the XFEL Working Group on Scientific and Technical Issues, the Technical Design Report was submitted to the International XFEL Steering Committee.
The planning of construction and operation of the European XFEL facility submitted by DESY to the German public authority in charge was approved.

2013
Commissioning of the X-ray laser after a construction period of approx. 6.5 years

XFEL: Facts & Figures

Free-electron laser that operates according to the SASE principle (self-amplified spontaneous emission)

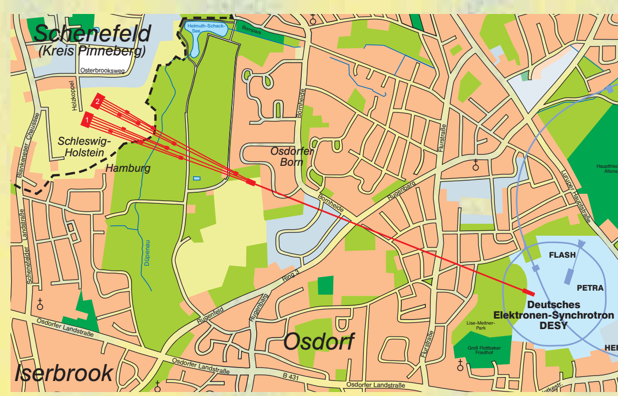
Total length of the facility:	approx. 3.4 km
Accelerator tunnel:	approx. 2.1 km
Depth underground:	6-38 m
Experimental hall:	10 measuring stations at 5 beamlines
(underground)	floor area ca. 4500 m^2, depth ca. 14 m
Plans for expansion:	second experimental hall with an additional 10 measuring stations

Wavelength of X-ray radiation: 6 to 0.085 nanometers (nm) corresponding to electron energies of 10 to 20 billion electronvolts (GeV)

Length of radiation pulses: below 100 femtoseconds (fs)

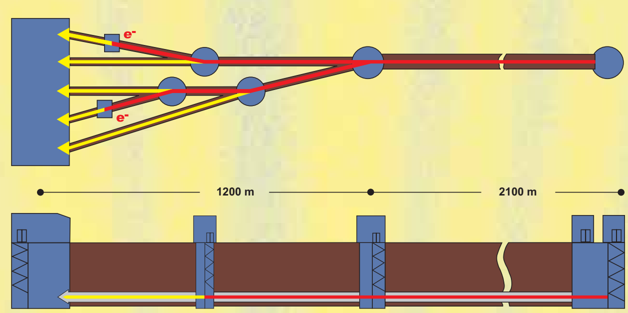
Costs

The total cost for the construction of the European XFEL facility including 10 measuring stations amounts to 986 million Euro based on year 2005 prices. This includes investment and personnel costs. As the host country, Germany covers up to 60% of the construction cost, at least 40% will be born by international partner countries.



Location of the XFEL

The three XFEL sites are located in the states of Hamburg and Schleswig-Holstein. The linear accelerator tunnel will beginn at the DESY site in Hamburg, where the supply stations will be built. The experiments will be carried out in an underground hall located in the south of the town of Schenefeld (Pinneberg district), which borders on Hamburg. Construction of a second experimental hall is planned on that site at a later date.



Schematic layout of the X-ray laser facility in a top and side view (not to scale). Red and yellow lines indicate electron and photon beamlines, respectively.

www.xfel.net