DESY.

DESY.

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association


DESY
Wir machen
Erkenntnis möglich

A strong cooperation partner

Training for top researchers

Large-scale facilities for science

Innovations for society

Research for the future

Impetus for the region

Title page: Resonators are being assembled in dust-free cleanrooms at DESY. These accelerator components, which are made of high-purity niobium, are used in accelerators of the latest generation to bring particles to extremely high energies.

INSIGHT STARTS HERE

DESY is one of the world's leading accelerator centres. Researchers use the large-scale facilities at DESY to explore the microcosm in all its variety – from the interactions of tiny elementary particles and the behaviour of new types of nanomaterials to biomolecular processes that are essential to life. The accelerators and detectors that DESY develops and builds are unique research tools. The facilities generate the world's most intense X-ray light, accelerate particles to record energies and open completely new windows onto the universe.

"DESY is one of the world's best centres for research with large-scale facilities and a key partner in international research cooperations. We intend to consolidate and expand this status."

Prof. Helmut Dosch, Chairman of the DESY Board of Directors

That makes DESY not only a magnet for more than 3000 guest researchers from over 40 countries every year, but also a coveted partner for national and international cooperations. Committed young researchers find an exciting interdisciplinary setting at DESY. The research centre offers specialized training for a large number of professions. DESY cooperates with industry and business to promote new technologies that will benefit society and encourage innovations. This also benefits the metropolitan regions of the two DESY locations, Hamburg and Zeuthen near Berlin.

DESY is a member of the Helmholtz Association, Germany's largest scientific organization. On behalf of society, the Helmholtz Association conducts research on urgent issues affecting our future.

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DESY


METROPOLITAN REGION
RESEARCH
LARGE-SCALE FACILITIES
DESY
TRAINING
INNOVATION
COOPERATION


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RESEARCH FOR THE FUTURE

The research carried out at DESY is extremely diverse. The scientists who work here are looking for the tiniest building blocks of matter that make up our world, developing innovative high-tech materials and searching for new mechanisms of action for future medications. As one of Germany's largest research centres, DESY carries out fundamental research that creates new knowledge and new conceptual approaches. This research is the basis on which the challenges of the future can be mastered: issues such as energy supply, climate protection and healthcare require long-term thinking, sustainable solutions and new technologies.

Research at DESY focuses on three areas:

> **Accelerators**
DESY develops, operates and utilizes state-of-the-art accelerator facilities. Scientists from all over the world use these facilities to investigate the structure and function of matter.

> **Photon science**
Several of the world's best light sources are located at DESY. Their special X-ray radiation makes atomic structures and reactions in the nanocosmos visible.

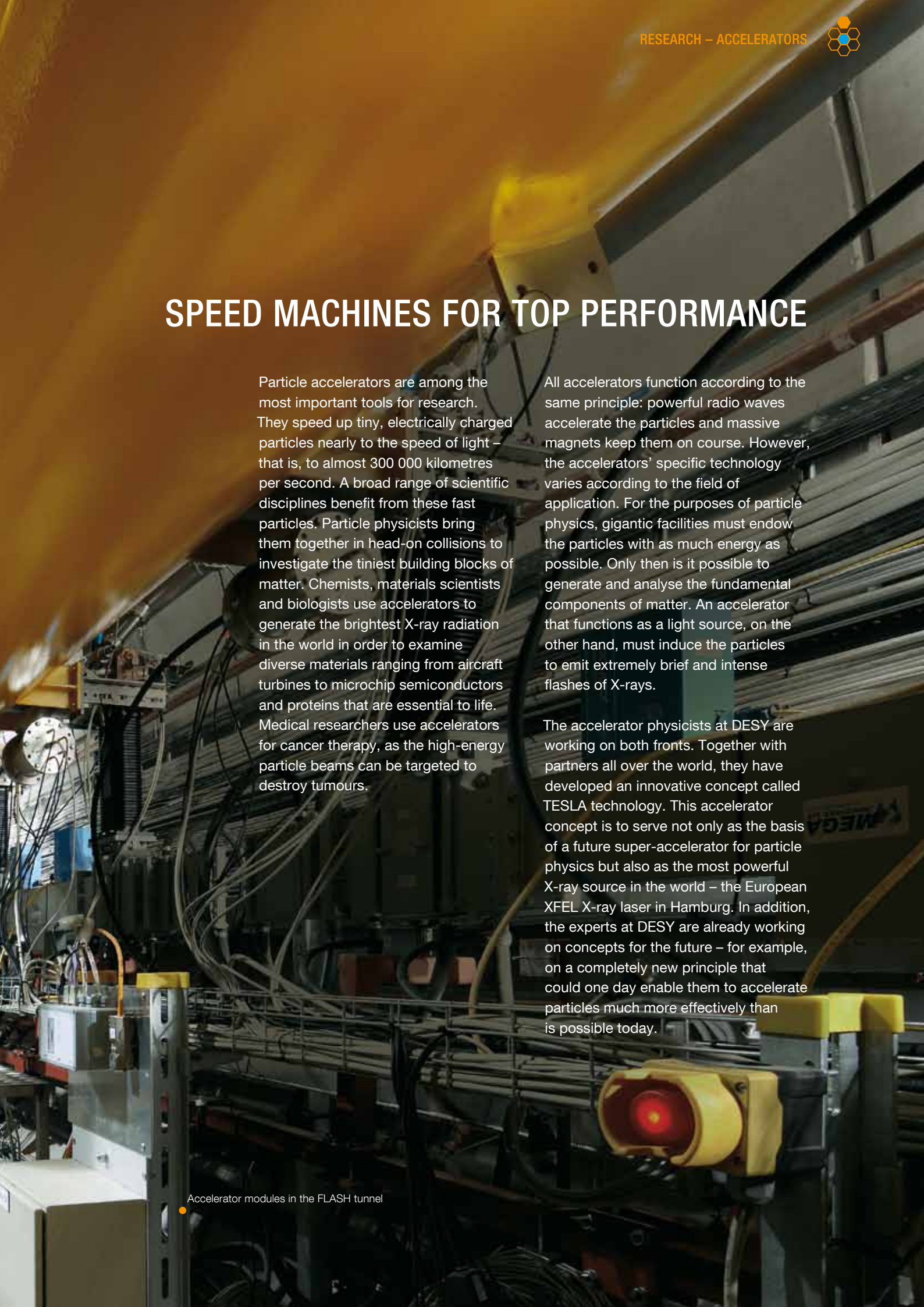
> **Particle and astroparticle physics**
In global cooperations and large teams, DESY scientists investigate the fundamental building blocks and forces of the universe.

SPEED MACHINES FOR TOP PERFORMANCE

Particle accelerators are among the most important tools for research. They speed up tiny, electrically charged particles nearly to the speed of light – that is, to almost 300 000 kilometres per second. A broad range of scientific disciplines benefit from these fast particles. Particle physicists bring them together in head-on collisions to investigate the tiniest building blocks of matter. Chemists, materials scientists and biologists use accelerators to generate the brightest X-ray radiation in the world in order to examine diverse materials ranging from aircraft turbines to microchip semiconductors and proteins that are essential to life. Medical researchers use accelerators for cancer therapy, as the high-energy particle beams can be targeted to destroy tumours.

All accelerators function according to the same principle: powerful radio waves accelerate the particles and massive magnets keep them on course. However, the accelerators' specific technology varies according to the field of application. For the purposes of particle physics, gigantic facilities must endow the particles with as much energy as possible. Only then is it possible to generate and analyse the fundamental components of matter. An accelerator that functions as a light source, on the other hand, must induce the particles to emit extremely brief and intense flashes of X-rays.

The accelerator physicists at DESY are working on both fronts. Together with partners all over the world, they have developed an innovative concept called TESLA technology. This accelerator concept is to serve not only as the basis of a future super-accelerator for particle physics but also as the most powerful X-ray source in the world – the European XFEL X-ray laser in Hamburg. In addition, the experts at DESY are already working on concepts for the future – for example, on a completely new principle that could one day enable them to accelerate particles much more effectively than is possible today.



Accelerator modules in the FLASH tunnel

High tech for highest energies

In a global effort, DESY physicists are developing an innovative accelerator technology

To accelerate particles to nearly the speed of light, a sophisticated technology is needed: specially shaped tubes into which powerful radio waves are fed. When electrically charged particles are sent through these resonators, they ride on the radio waves like surfers on ocean waves. In the process, the particles – electrons, for example – are given a boost and accelerated to high energies.

Together with 50 institutes from 12 countries, DESY has been developing a particularly effective accelerator concept – called TESLA technology – since the 1990s. Unlike conventional facilities, the TESLA resonators are superconducting and therefore operate almost without any energy loss: the energy of the electromagnetic fields is transferred almost entirely to the particle beam. However, the resonators function only under extremely cold conditions and are therefore installed in heat-insulated tubes. Inside these tubes, helium cools the temperature to approximately minus 271 degrees Celsius – a superlative refrigerator.

To demonstrate that this technology works and refine it further, the international team built a test facility in Hamburg, which was almost 100 metres long. The joint pilot project was a success. “We managed to unite all the world’s experts working on superconducting accelerators into a single team,” says DESY physicist Hans Weise. “Without these partners, it’s doubtful whether we could have developed this sophisticated technology.”

Today, the free-electron laser FLASH is based on TESLA technology; starting in 2015, more than 800 superconducting TESLA resonators will be used in the European XFEL X-ray laser. And research activities are ongoing. The international partners are currently working on making the TESLA resonators even more powerful and cost-effective. The team is also looking for new applications – for example, in facilities that accelerate hydrogen nuclei instead of electrons.

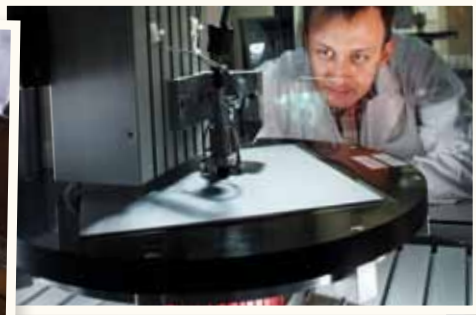
“In our international team, we have developed an accelerator technology that is setting benchmarks worldwide.”

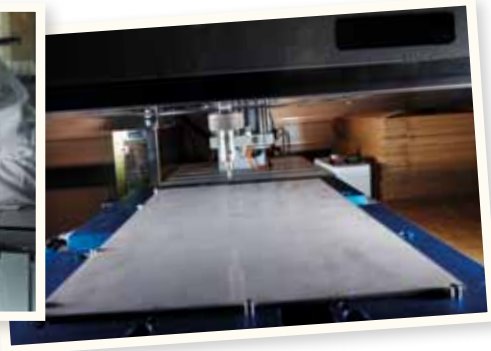
Dr. Hans Weise, accelerator expert at DESY

Resonators in a cleanroom

A niobium cylinder weighing tonnes must pass through the smelting facility six times before it is considered pure enough to be processed further.

At DESY, all the niobium sheets are gathered together and subjected to quality inspection.





A scanner checks the surface for impurities and unevenness.

After the sheets have been formed into resonators, they have to pass further quality tests.

Special 3D software makes it possible to take a virtual stroll through the accelerator before it even exists.

Changing shifts in the cleanroom. The air here is almost completely free of dust.

From niobium sheet to precision component

How a TESLA accelerator module is made

The European XFEL X-ray laser will rely on accelerator modules of the latest generation. The concept behind these superconducting resonators was developed by an international team led by DESY and refined until it was ready for application. Construction of the accelerator complex is now well under way. Institutes and companies are preparing for the series production of the 101 modules, each of which will house eight resonators made of the metal niobium. The manufacture and assembly of these high-tech components are extremely complex. The very highest precision and quality are required so that the electron beam can later be accelerated to the desired energy.

The individual resonators are gradually becoming a string; eight of them are built into one accelerator module.

Before the resonator string is installed in the accelerator module, other important elements, such as helium lines, are added.

The finished modules are installed in the accelerator.

More power with plasma waves

Accelerator concepts for the future

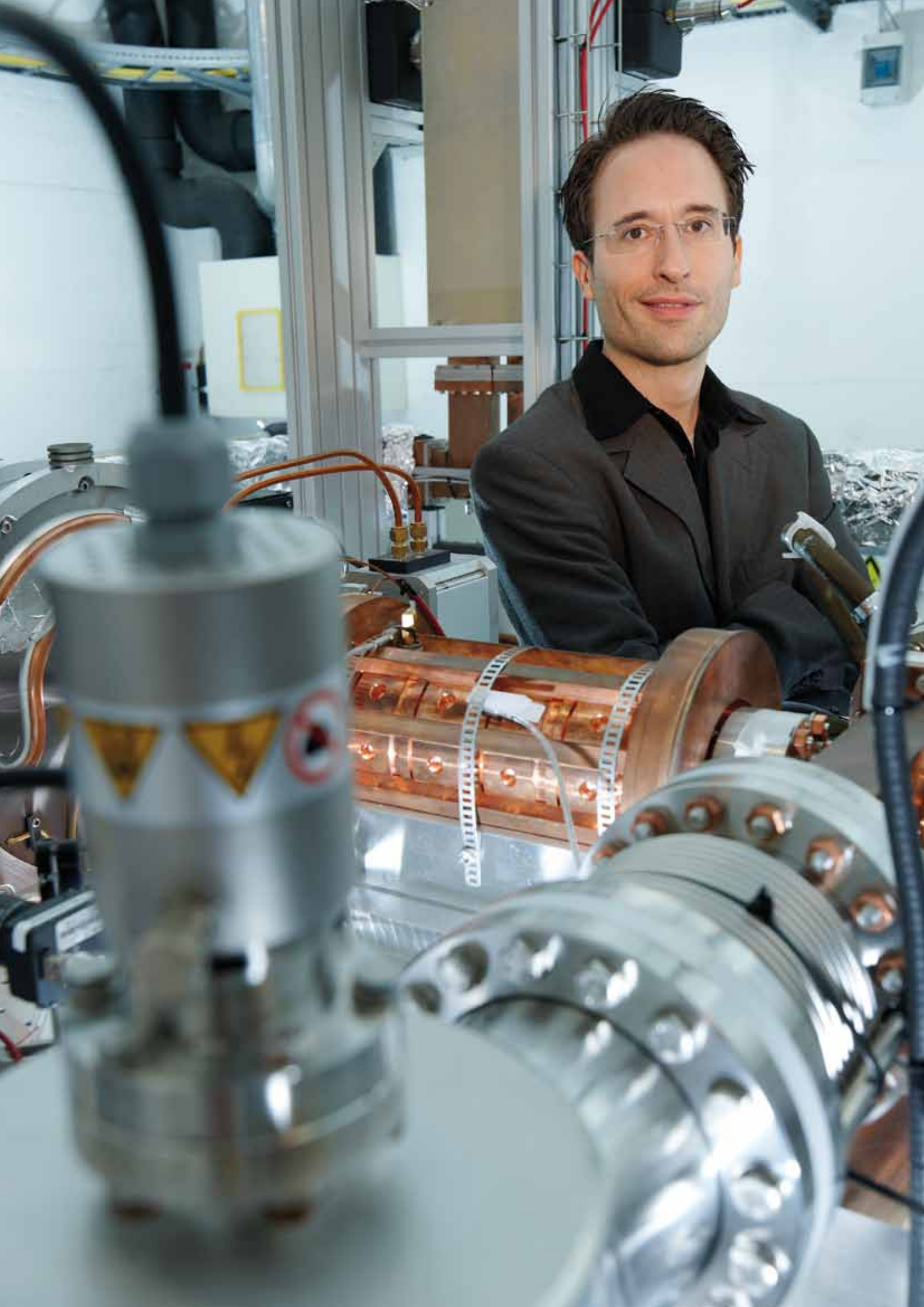
Accelerating particles ever more powerfully and efficiently – that's the goal experts around the world are working toward. To date, they have been setting their hopes on resonators – specially shaped tubes in which powerful radio waves accelerate the particles. The disadvantage of this technology is that it will probably reach its performance limits in the foreseeable future. That's why researchers at DESY are working together with the University of Hamburg on an alternative concept: plasma accelerators. One day they may boost particles to extremely high energies over a comparatively short distance, thus opening new vistas for research.

This is how a plasma accelerator works: A powerful laser sends a flash of light into a gas, transforming it into a plasma. Next, the laser fires a second, even stronger pulse into this plasma. The second pulse generates a kind of plasma wake that can pull electrons along with it and accelerate them, like surfers riding an ocean wave. This acceleration is considerably greater than what can be generated by present-day facilities.

The concept is still in its infancy, however. So far, plasma acceleration has not functioned reliably enough. Crucial questions remain unanswered – for example, whether and how multiple individual accelerators can be connected in series. To answer these questions, experts from DESY and the University of Hamburg have joined to form the LAOLA team. "Among other things, we want to send the electron bunches from the existing DESY accelerators into the plasma waves so that we can investigate them in detail," explains Florian Grüner from the University of Hamburg. Experiments like these could one day lead to a new generation of accelerators – facilities that are only a few metres rather than many kilometres long, yet deliver the same performance.

"Whereas today's facilities are kilometres long, we would need only a few metres – it would be a whole new world!"

Prof. Florian Grüner, University of Hamburg

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THE NANOCOSMOS IN X-RAY LIGHT

When a doctor takes an X-ray, he generates an image of the interior of the patient's body, allowing him to determine, for example, whether a bone has been broken as a result of an accident. Scientists too benefit from the penetrating capability of X-rays. For example, when physicists X-ray nanomaterial samples, they see not only which types of atoms are present but also how the atoms are arranged. Chemists use X-rays to precisely analyse what happens during catalysis – a process of enormous economic importance. Biologists work with X-rays to reveal the structures of proteins in order to better understand the causes of illness and develop better treatments.

Conventional X-ray tubes like those used in hospitals are generally not suitable for today's scientific applications, because the X-rays they generate are too weak for the experiments. Particle accelerators, on the other hand, generate extremely powerful and focused radiation. These X-ray beams are so intense that even the finest details can be seen – for example, the tiniest cracks and pores in a turbine blade, minute impurities in a semiconductor, or the positions of individual atoms in a protein molecule. Moreover, when researchers fire extremely short X-ray flashes at various samples, they are able to observe ultrarapid processes such as those that occur in a chemical reaction.

Some of the world's best light sources are located at DESY in Hamburg: the PETRA III storage ring generates brilliant X-ray light for various experiments; the FLASH free-electron laser produces ultrashort laser pulses in the X-ray range; and the European XFEL X-ray laser will begin operation in 2015 as a true super-microscope. These three facilities make DESY a magnet for top-level research.

PETRA III experimental station

Golden age for solar energy

DESY research improves solar cells

The application possibilities for solar cells that are as bendable and inexpensive as plastic film are truly exciting. Windows could be lined with solar films that produce electricity, and solar-cell-coated backpacks could be used to recharge mobile phones and MP3 players. However, the technology for such applications is still in its infancy. At present, these organic solar cells are not particularly energy efficient and do not exhibit long service lives. DESY researchers are striving to improve their properties.

Organic solar cells are made of electrically conductive plastics. To tap the current they produce, they must be fitted with electrical contacts, which are made of conductive metals such as gold. As a rule, the better the bond between the gold contacts and the plastic, the greater the amount of energy that can be reaped. A team led by DESY scientist Stephan Roth is using X-rays from PETRA III to precisely examine how gold and plastic bond. Technische Universität München provided the prototypes for the organic solar cells, which were coated at DESY using a special technique known as sputtering.

Solar energy is clean and safe.

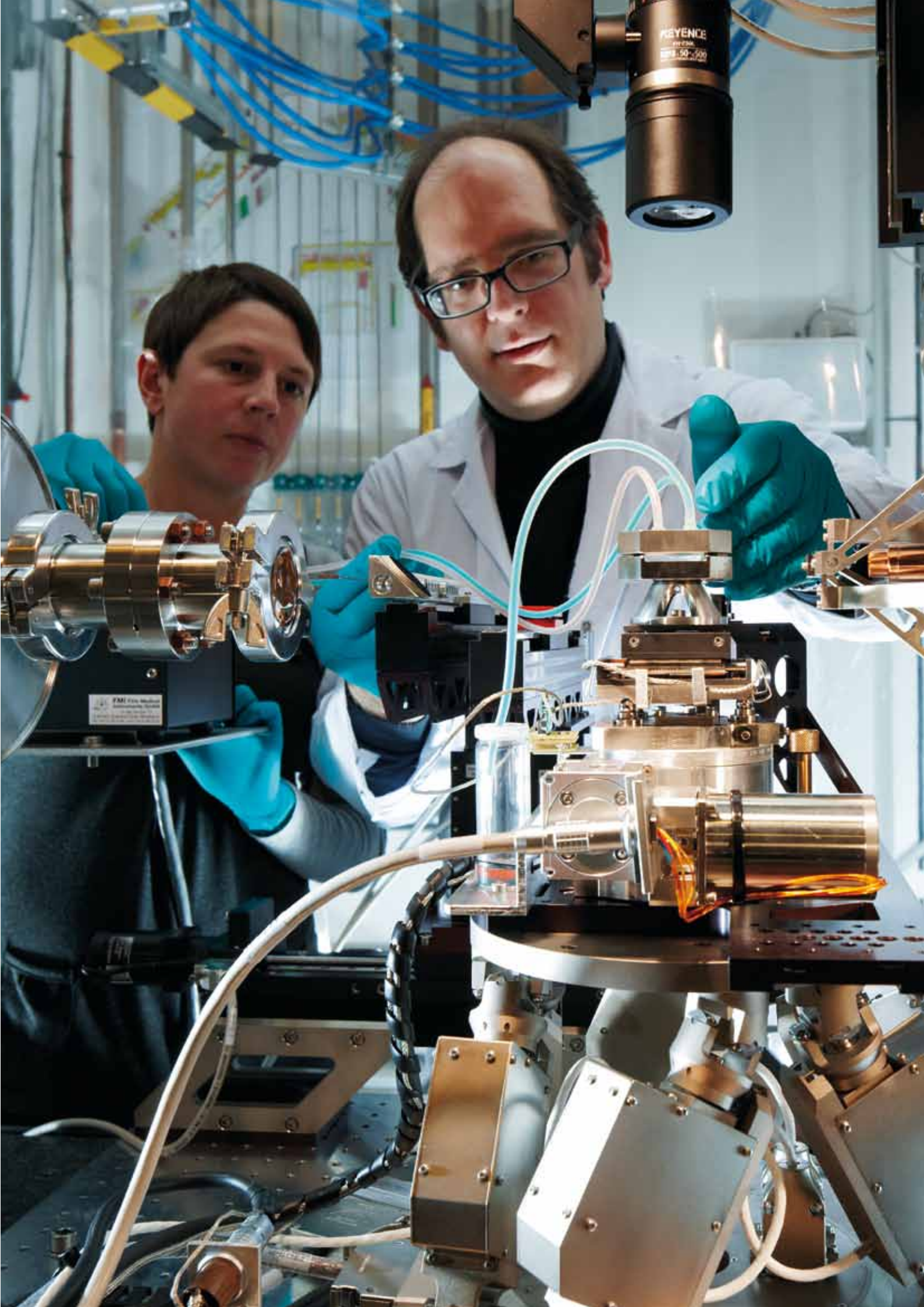
During sputtering, fast noble gas ions collide with a gold coating in a vacuum chamber and kick out individual gold atoms, which strike the organic solar cells. Some of the gold atoms penetrate slightly into the plastic; others remain on the surface and merge into small nanometre-scale islands. These form the nuclei for the contacts.

"The intense and extremely fine X-ray beam from PETRA III enables us to monitor the entire production process in detail," Roth explains. "No other method will work here." The experts can watch more or less live how the nanoislands form, and these observations give them important clues as to how the production process can be optimized to ensure the best contacts possible.

"Here at DESY, we can produce gold coatings under industrial-like conditions and observe what happens in real time during the process."

Dr. Stephan Roth, DESY physicist

Through their experiments, the physicists were also able to confirm an important mechanism. They discovered that the contact the gold atoms create is not limited to the surface of the solar cell; the gold atoms also penetrate into the cell at the metal/polymer barrier layer. "It's a phenomenon that we saw for the first time on model solar cells here at DESY," says Roth. "We expect it will help to further improve the efficiency of organic solar cells."


KEYENCE

Ribosomes revealed with X-rays

Israeli Nobel Prize Laureate conducted research at the DORIS accelerator

"DESY very generously provided us with beam time even in the 1980s, when our project met with worldwide scepticism as it was widely assumed that the structure of the ribosome might never be determined."

Prof. Ada E. Yonath, 2009 Nobel Laureate

The highest scientific honour was bestowed upon Israeli biochemist Ada Yonath in Sweden, but decisive experiments that led to the award were carried out at DESY in Hamburg. It was here that Yonath studied the ribosome using highly intense X-ray radiation and that she was able to identify in detail the structure of this vital molecule complex. Yonath and two colleagues received the Nobel Prize in Chemistry in 2009 for their achievement.

The ribosome – a molecular complex made up of numerous biomolecules – plays a key role in the human body as the protein factory in each and every cell. The design is determined by DNA, and the building blocks the ribosome uses are amino acids, which it links in chains to form proteins, the fundamental components of life.

To understand in detail how the ribosome functions, you need to know its exact structure – in the best case, the arrangement of the individual atoms it consists of.

Yonath attempted to solve the puzzle using X-ray crystallography. Over a period of years, she exposed thousands of ribosome samples to powerful collimated X-ray beams, some of which were provided by the DORIS accelerator at DESY. The ribosome atoms scattered the X-rays in a specific manner. Special detectors were used to record the reflected X-rays, thereby allowing the researchers to reconstruct the exact locations of the atoms in each molecule.

However, the scientists had to be patient, as transforming the ribosome into crystals – the basic requirement for successful experiments – proved to be very difficult.

Yonath finally came up with the solution in her native Israel – more specifically in the Dead Sea, whose temperature can reach 60 degrees Celsius and whose water is extremely salty. "Bacteria do live in it, however," says Yonath. "Their ribosomes were so resistant that we were able to grow them into crystals that we could use for our studies." She later examined how antibiotics bind with the ribosomes of bacteria in order to block them. Her experiments now form the basis for the development of new medications.

Van Gogh's hidden pictures

DESY scientists analyse works of art

It's often difficult for art historians to determine whether an old painting really is the work of a famous master. DESY physicists can offer valuable help here, because their X-ray sources can provide new and informative evidence regarding the author of a particular work. The X-ray beams can also reveal whether a master painted over an older picture because he didn't like it anymore or perhaps didn't have the money for a new canvas.

Art historians remain unsure as to whether the work known as "Pauline" really was painted by Philipp Otto Runge, one of the most important German painters of the early Romanticist period. A discovery made using a DESY accelerator may have found the answer. Researchers used X-rays from the accelerator to scan the painting point by point. During the process, the X-rays caused the chemical elements in the picture to briefly fluoresce. Because every pigment used by a painter lights up in a unique way, it is possible to view pigments the artist may have painted over. This X-ray fluorescence analysis of "Pauline" revealed that the actual painting, which shows a young, dreamy woman standing in front of a forest landscape, is hiding something underneath – the same woman with different clothing and a different hair-style. The hidden painting is similar to several drawings that Runge made of his sister – evidence that the painting is genuine.

In a great example of successful inter-disciplinary research, DESY physicists cooperated with art historians from Delft, Otterlo and Antwerp to achieve similar results with other works by Vincent van Gogh and Rembrandt.

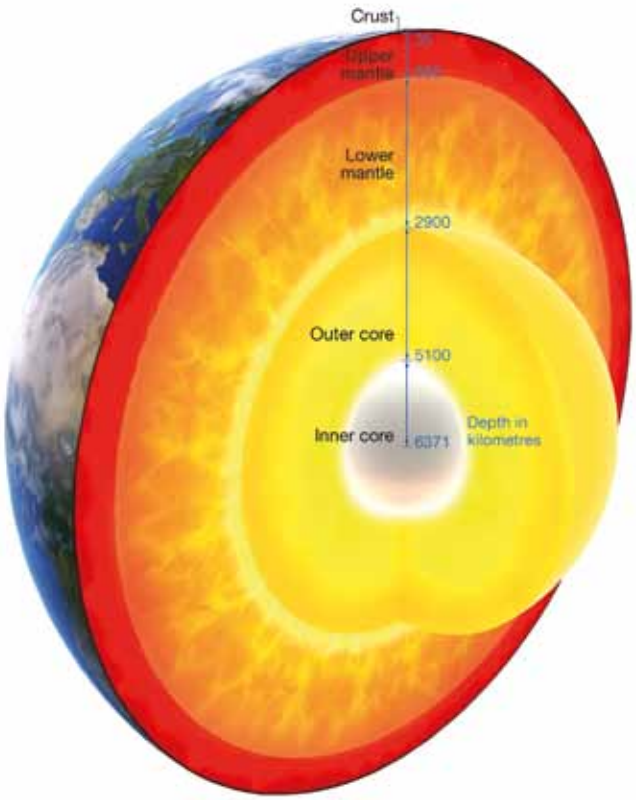
An international research team used X-ray light from the DORIS accelerator to illuminate the van Gogh painting "Grasgrond." The researchers found a painted-over portrait of a woman.

Rocks under pressure

Geological researchers at DESY simulate events deep inside the Earth

What does the interior of our planet look like? This, perhaps the most exciting question in the field of geology, can only be answered indirectly because scientific boreholes only “scratch” the Earth’s crust. At least, the extreme conditions inside the Earth can be simulated in a lab. At DESY, experts from the Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences put tiny rock samples under high pressure to study them using extremely intense X-ray radiation.

The interior of the Earth is marked by extreme pressure and temperatures of 2000 degrees Celsius. These conditions can be simulated at DESY.



The conditions that reign several thousand kilometres below the surface of our planet are extreme. The pressure is 250 000 times higher than that of the atmosphere and temperatures climb to 2000 degrees Celsius. The scientists use hydraulic hard-metal stampers to reproduce these conditions. The stampers crush rock samples much smaller than a sugar cube from all sides, while powerful focused X-rays from the accelerator shoot through slits located between the stampers into the rock. An analysis of the scattered X-rays then reveals how the mineral’s crystal structure changes under pressure.

This method enabled the geo-researchers to find out that the mineral olivine – an important component of the Earth’s mantle – is transformed into another type of rock called spinel when the pressure rises above a certain level. The mineral’s volume shrinks by one-tenth in the process, which would explain certain irregularities discovered during seismic studies of the mantle. The experts are also able to create artificial magma and analyse its properties. The accelerator’s X-rays reveal how viscous the molten rock is at certain pressures. This important information helps scientists to understand how quickly magma can build up underneath volcanoes.

Living muscle cells in X-ray light

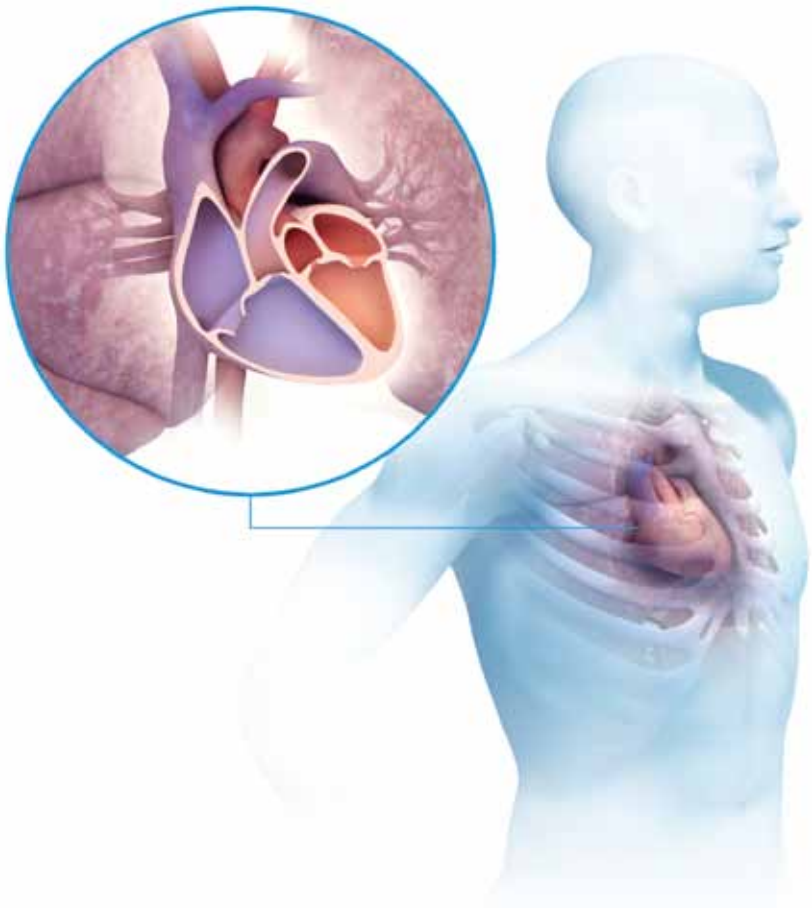
Researchers at DESY are looking at the causes of heart disease

Around one out of every 500 Germans suffers from hypertrophic cardiomyopathy (HCM), a disease of the heart muscle that causes the walls of the left ventricle to thicken significantly. The condition leads to heart rhythm disorders of varying degrees, and in some cases can result in heart failure or sudden cardiac death. Researchers at Hannover Medical School are attempting to determine the causes of this genetic disease. Among other things, they are using highly intense X-ray radiation from the DESY accelerators to study defective heart muscle cells.

The results from basic research could lead to completely new treatments for heart disease.

People afflicted with HCM have a genetic defect which alters the protein molecules that regulate heart muscle contractions, one of which is myosin – the so-called motor protein. The extent to which altered motor proteins function differently than healthy ones remains unclear, however, as does the reason why they lead to HCM. To answer these questions, scientists are exposing living heart muscle cells from HCM patients and healthy people to intense, collimated X-ray beams. These allow them to see what the cells look like in detail. The scientists can then determine, for example, if defective motor proteins are arranged differently than healthy ones in the muscle cells and to what extent their structure and function are altered.

The researchers have found out that the head of a defective myosin protein is much stiffer than that of a healthy one, which leads to differences in strength. Every HCM patient has both healthy and defective myosin; the difference, as researchers have shown, lies in their proportions relative to one another. The two types of protein are also unequally distributed in the heart muscle, which leads to an imbalance in muscle cell strength. Some of the muscle cells work better than others. As a result, the heart muscle itself doesn't function smoothly and eventually becomes damaged. Specialists are hoping these discoveries will assist with the development of new treatments over the long term. One promising strategy might be to shut down the defective genes and thus suppress the production of malfunctioning motor proteins.



The heart consists of two superior atria and two ventricles. The heart muscle needs to be healthy in order to pump blood continually through the body.

World record with FLASH

Using the Hamburg X-ray laser, researchers have shot the fastest film in the world

"The long-term goal is to observe the motion of molecules and nanostructures in real time."

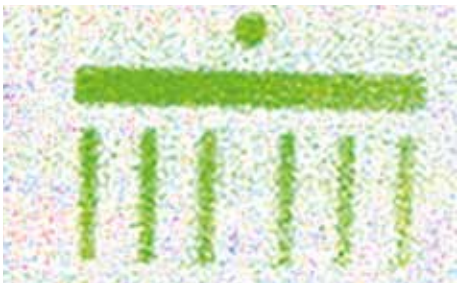
Prof. Stefan Eisebitt, Technische Universität Berlin and Helmholtz Centre Berlin

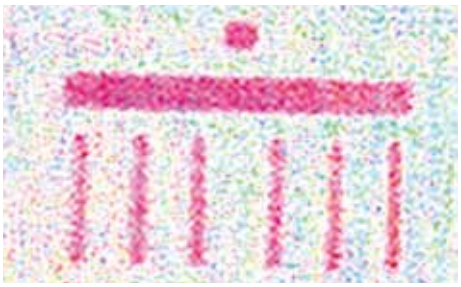
When you watch a film, you're actually experiencing an optical illusion because the film doesn't run continuously but instead presents 24 still images per second. That's fast enough for the brain to perceive the images as uninterrupted movement. The "films" that physicists working with the FLASH laser in Hamburg have made are much faster than a normal Hollywood movie. Here, individual images are recorded at intervals of 50 femtoseconds, which equates to less than one ten-thousandth of a billionth of a second – a new world record. The technique enables researchers to observe extremely rapid processes in the nanocosmos.

The feat is made possible by the ultrashort X-ray pulses generated by FLASH. Each FLASH pulse is intense enough to record an image – much like an ultrafast stroboscope. The problem is that today's camera sensors are much too slow to capture such an extremely rapid sequence of images. To get around this, the physicists from Technische Universität Berlin employed a special method: holography.

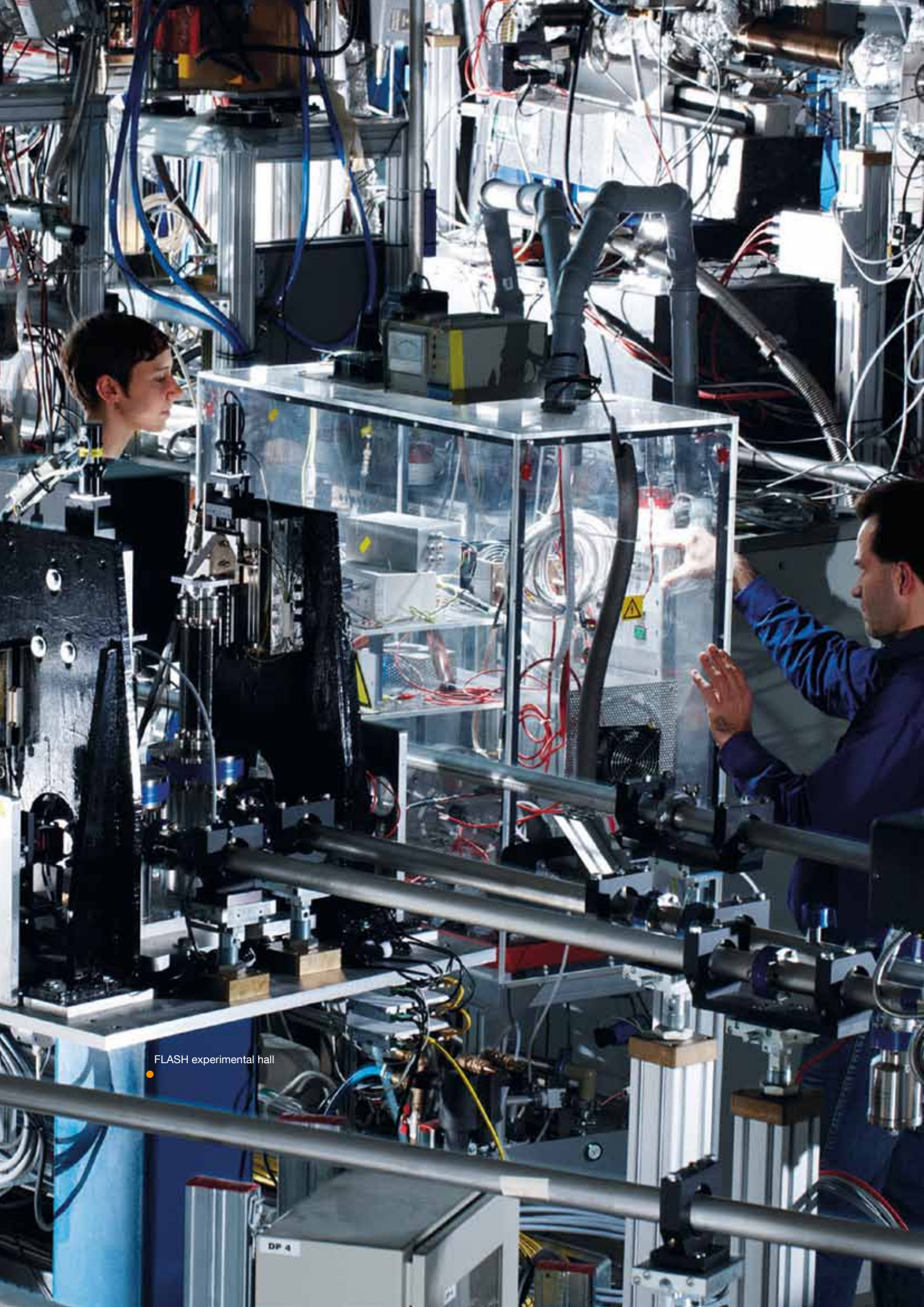
"Holography makes it possible to store several images in a single recording," says project leader Stefan Eisebitt.

Holograms generally store various angles of view of an object – for example, an apple. When looked at, the apple seems amazingly spatial, like a 3D image. Using clever tricks, the researchers were able to hold several different moments rather than several points of view simultaneously on the camera sensor. To demonstrate the feasibility of the procedure, they experimented with a test image in the form of a tiny picture of Berlin's Brandenburg Gate etched into a metal film. They were able to record two images at an interval of 50 femto-seconds. It was no more than a mini slide show – but nevertheless the fastest one on the world. "In principle, you could record more images," says Eisebitt. The researchers now plan to watch how nanometre-sized magnets change their magnetization at ultrafast speeds. Their findings will play an important role in the design of future computer hard disks.





Reconstructed images of the Brandenburg Gate model



FLASH experimental hall

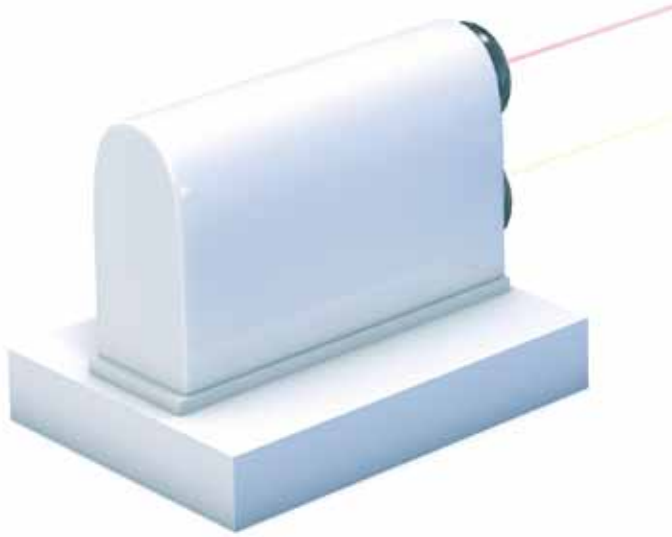
The world's most powerful X-ray flashes

The European XFEL will enable completely new experiments

Films of chemical reactions that take place in fractions of a second, images of proteins in which every atom can be seen, pictures of nanomaterials that show the tiniest details, insights into the states of matter inside giant planets or stars – up until now, scientists could only dream of conducting such experiments. Beginning in 2015, however, the European XFEL X-ray laser will make this dream come true. The large-scale facility is currently under construction. When completed, it will be the world's brightest X-ray source, with X-ray flashes that will be up to a billion times more intense than those produced using today's accelerator-based sources.

The European XFEL, which is being installed in underground tunnels, will be more than three kilometres long and stretch from the DESY site in Hamburg to the town of Schenefeld in the German federal state of Schleswig-Holstein. The billion-euro project is an international joint undertaking for which a separate company was established, the European XFEL GmbH. The project is being conducted by Germany and 11 other countries, including Russia, France and Italy.

The European XFEL generates up to 27 000 laser flashes per second. These flashes are billions of times more intense than anything the best conventional X-ray sources can produce.



Molecular cinema: how to film a chemical reaction
In an effort to monitor chemical reactions, researchers plan to use the incredibly short X-ray flashes – they last less than a trillionth of a second – generated by the European XFEL. The principle works as follows: A light pulse (1) triggers the chemical reaction. Shortly after, an X-ray laser flash (2) generates an image, and a detector records what occurs during the reaction. A series of such snapshots at different intervals produces a "film" of the reaction.

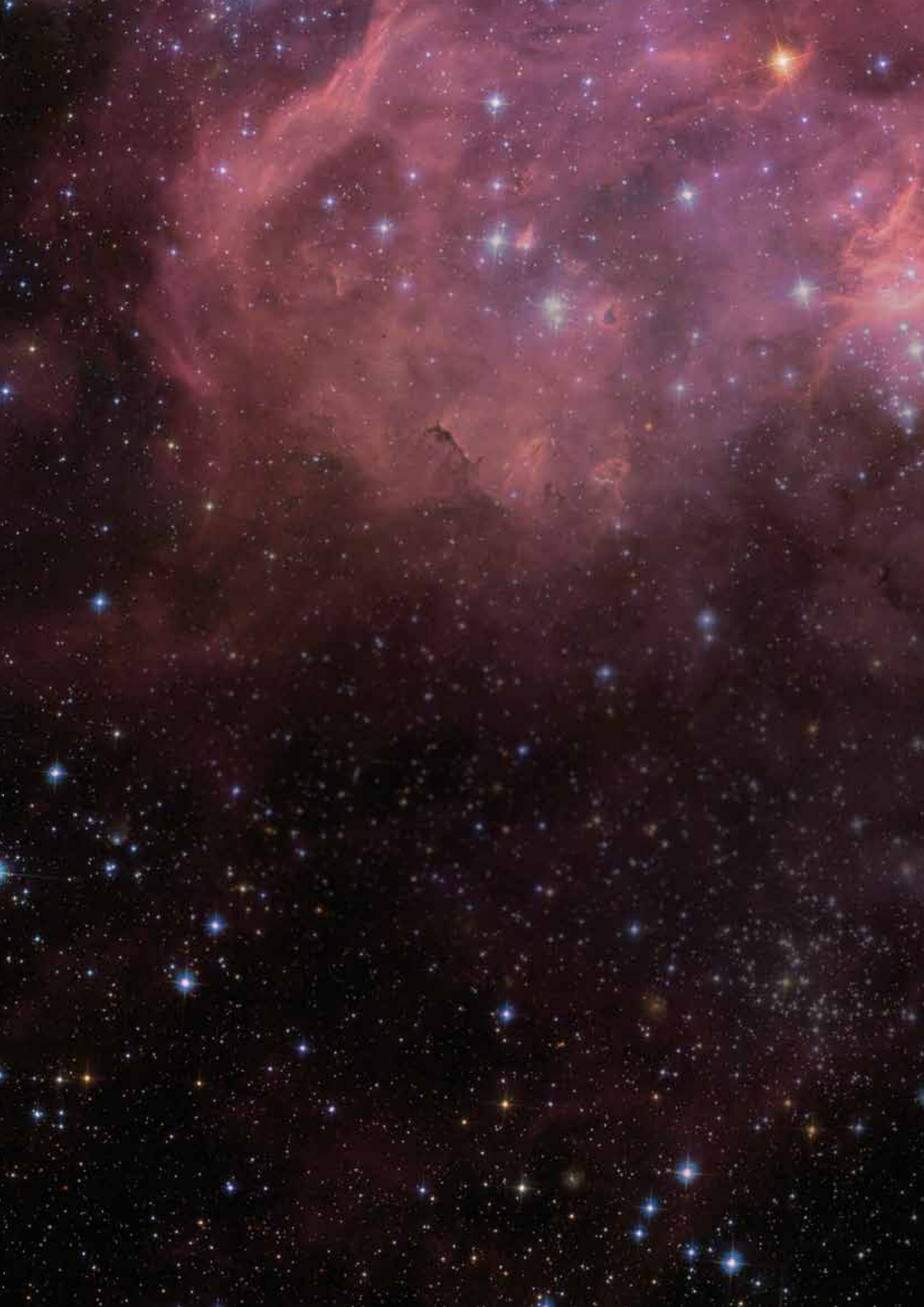
Scientists from a range of disciplines will benefit from the new super-laser:

Biologists will obtain detailed images of cell components, individual protein molecules and viruses. The results will help to combat diseases and develop new medications.

Chemists will film reactions and observe in slow-motion how individual atoms react with one another. The knowledge thus gained can help to optimize industrial catalysts, for example.

Physicists and materials scientists will study the exact structure of nanomaterials. Such materials play an important role when it comes to developing more effective solar cells, fuel cells and data storage systems.

Astrophysicists will analyse extremely hot and compressed material samples. This will provide insights into the interior of stars and planets and help reveal the extent to which nuclear fusion processes are suitable as a new source of energy.



HOW DOES THE UNIVERSE WORK?

What does the world consist of at the smallest level? What are the most fundamental particles of matter? Natural scientists have been looking into these basic questions since antiquity. In the course of their search, they have encountered ever smaller building blocks – first atoms, then atomic nuclei consisting of protons and neutrons, and finally tiny particles called quarks. Today, particle physicists are investigating the fundamental mysteries of the universe: what holds the cosmos together, and how do particles acquire their mass in the first place?

When DESY was founded in 1959, the primary task of the centre was to investigate the smallest particles. Over the decades, DESY has put into place central pieces of the mosaic of particle physics. With the PETRA storage ring, researchers discovered the gluon, the "glue particle" that holds the quarks together and without which there would be no atoms. Later, they used the HERA accelerator to investigate the proton with unprecedented precision. The surprising result: the inner workings of this particle, which is so important for our world, turned out to be much more complex than expected.

Today, a number of DESY researchers are taking part in the experiments currently attracting so much attention at the LHC in Geneva, the most powerful accelerator in the world. Others are peering deep into the cosmos. Using spectacular detectors and telescopes, the experts are analysing exotic particles that come from far corners of the universe and could provide information about fascinating phenomena, such as black holes, exploding stars and inconceivably intense eruptions of radiation.

In search of Higgs & Co.

The European research centre CERN operates the LHC, the most powerful accelerator in the world

It's the most ambitious project that particle physicists have ever undertaken. Since 2010, the Large Hadron Collider (LHC) at the CERN research centre in Geneva has been providing extremely interesting data. This huge machine – the most powerful accelerator in the world – is located in a 27-kilometre-long subterranean ring tunnel. It accelerates protons to unprecedented energies and makes them collide head-on with one another. These collisions can give rise to exotic, short-lived particles that reveal what fundamental building blocks the world is made of. Complex detectors as large as office buildings monitor the proceedings. DESY physicists take part in these experiments, sometimes in leadership roles.

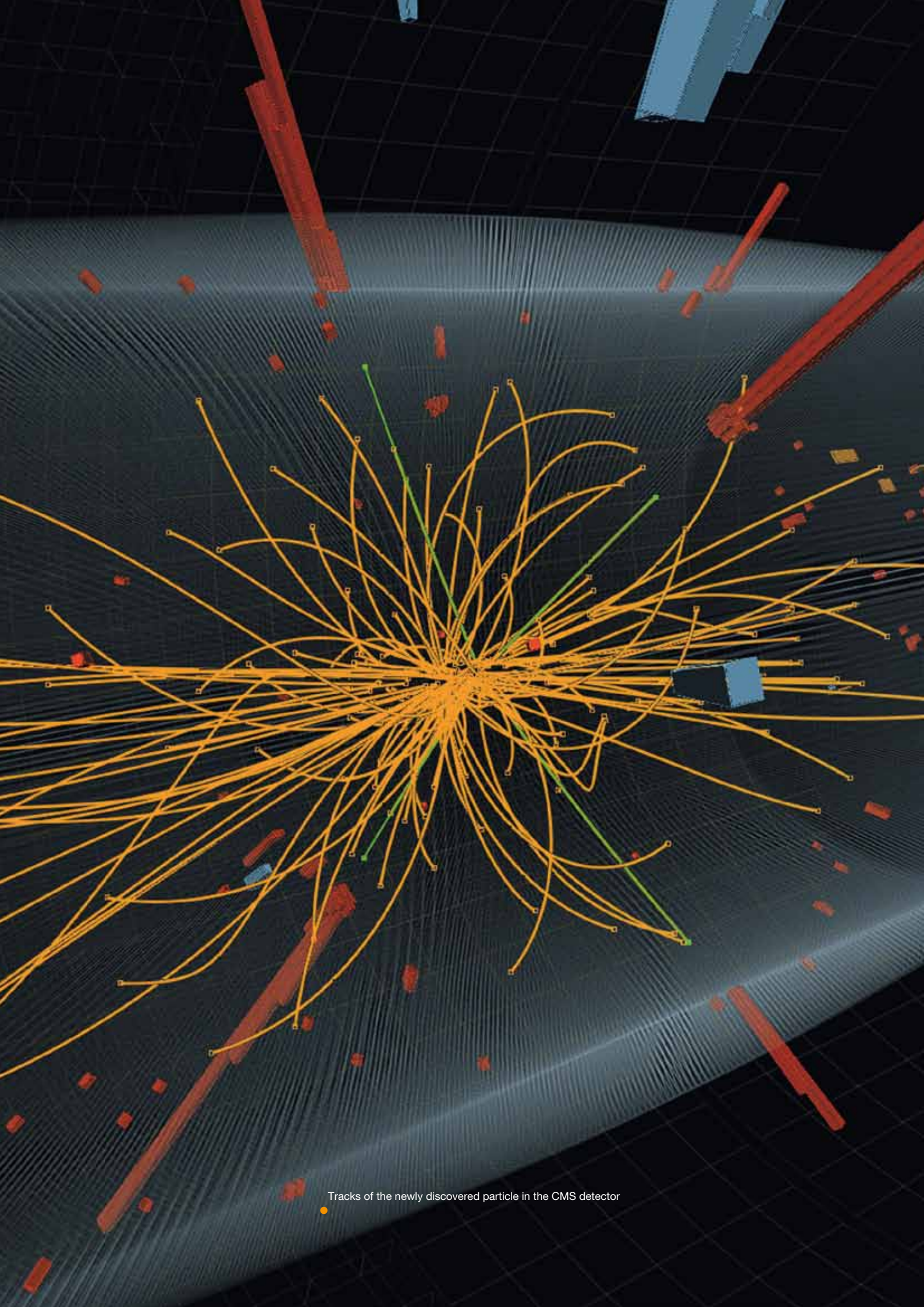
"For me, the hints of the Higgs particle are the discovery of the century so far. What I find most convincing is that we see the same signal in two independent sets of data, and we see it consistently in both experiments, ATLAS and CMS."

Prof. Joachim Mnich, DESY Director for High-Energy Physics and Astroparticle Physics

With its record-setting energy, the LHC is expected to answer some of the most exciting questions in physics, for example: how do elementary particles acquire their mass? An answer was proposed by the Scottish physicist Peter Higgs and others. According to them, the cosmos is permeated by a special field that operates in a manner similar to honey when a spoon moves through it: it offers the particles due resistance and thereby makes them "heavy". If the theory is correct, there has to be a special particle, the Higgs boson. And indeed, in the summer of 2012, the LHC quite likely detected it.

But the largest scientific machine in the world could also detect entirely different, so far merely speculative phenomena. One fascinating result would be the discovery of SUSY particles. These could play a major role in the universe. By virtue of their gravitational force, they could hold the galaxies together like invisible glue – the experts refer to "dark matter" in this context. And the LHC might also provide evidence that our world is not just four-dimensional – three spatial dimensions and time. The cosmos could instead have significantly more dimensions. These however would be so well hidden that a super-accelerator like the LHC is required to even detect signs of their existence.

The detectors ATLAS (left) and CMS (right) have found mutually consistent indications of the Higgs particle.



Tracks of the newly discovered particle in the CMS detector

Beyond the Standard Model

DESY theorists are forging a new view of the world of physics

Today particle physicists have a very detailed view of what makes up matter at the smallest level. We ourselves and all of the materials around us consist of indivisible elementary particles – electrons and quarks. The latter combine to form neutrons and protons and make up the atomic nuclei. The atomic nuclei, in turn, are surrounded by shells of electrons. Together the nuclei and electrons form atoms and thus elements like hydrogen, sulphur or iron.

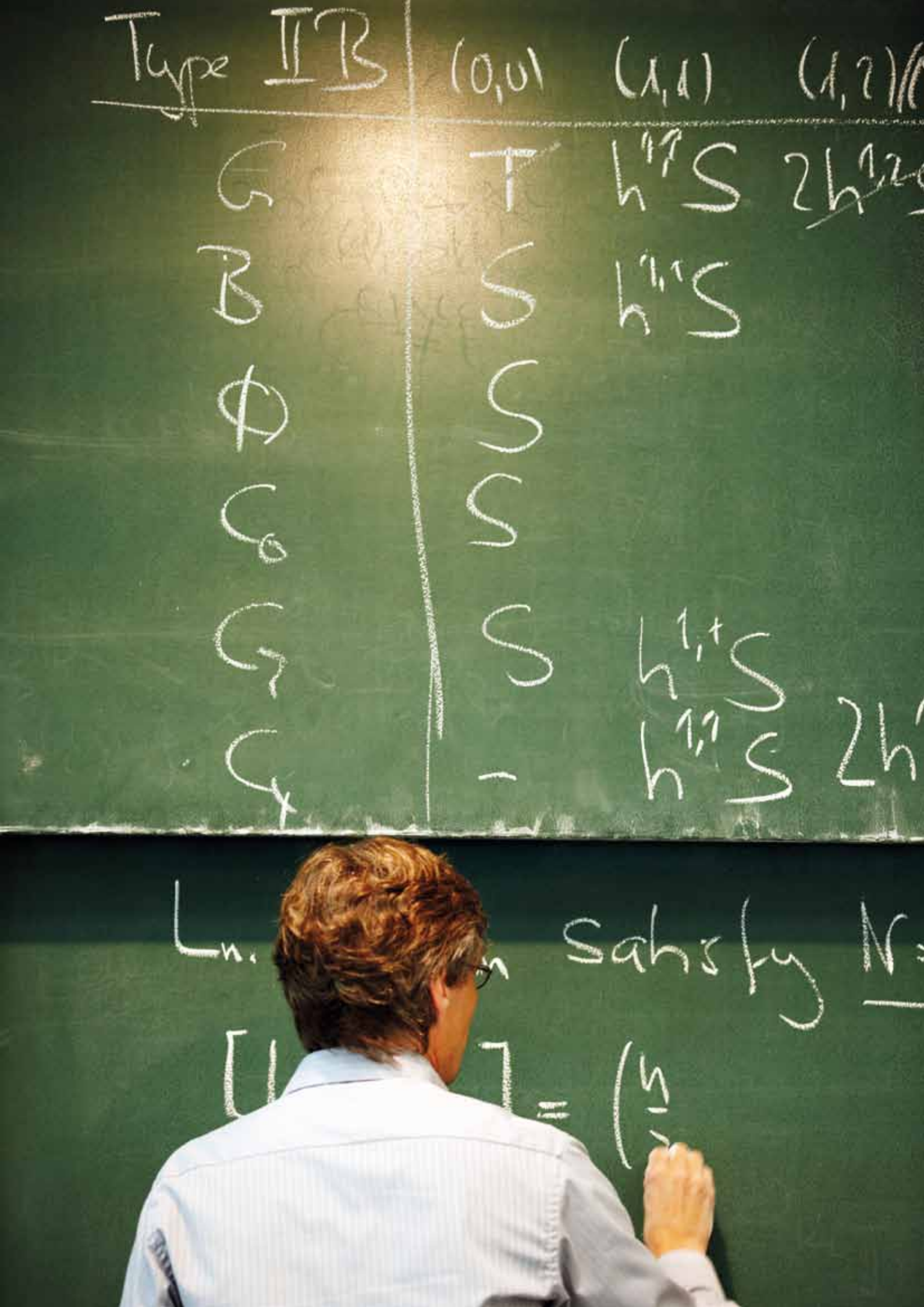
The Standard Model comprises 12 elementary particles, four force particles and the Higgs particle. But some physicists believe that each of these particles has a heavy, so far undiscovered partner – the supersymmetric particles.

The particles of matter are held together by various forces of nature, including the electromagnetic and strong forces. In addition, physicists know other, more exotic particles – such as neutrinos, or several sorts of heavy, unstable quarks.

Physicists summarize what they know about the structure of matter in the Standard Model, which has stood up remarkably well in countless experiments. In all probability, the super-accelerator LHC in Geneva detected the particle missing from this model in the summer of 2012: the Higgs boson, which helps the other particles acquire mass. But some theorists are already one step further. They are forging theories that are even more comprehensive and more fundamental than the Standard Model.

One example is SUSY, or supersymmetry. This theory would, for the first time, bring the elementary particles and the forces of nature together in a single mathematical framework. If super-symmetry is correct, then there must be SUSY particles – and the LHC is looking for these exotic particles too. String theory goes much further still. According to this theory, the world could consist of inconceivably small threads that oscillate like the string of a violin and in so doing form quarks and electrons.

With the HERA accelerator at DESY, physicists discovered that the structure of the proton is much more complex than previously supposed: instead of just three quarks, it consists of a “sea” of elementary particles.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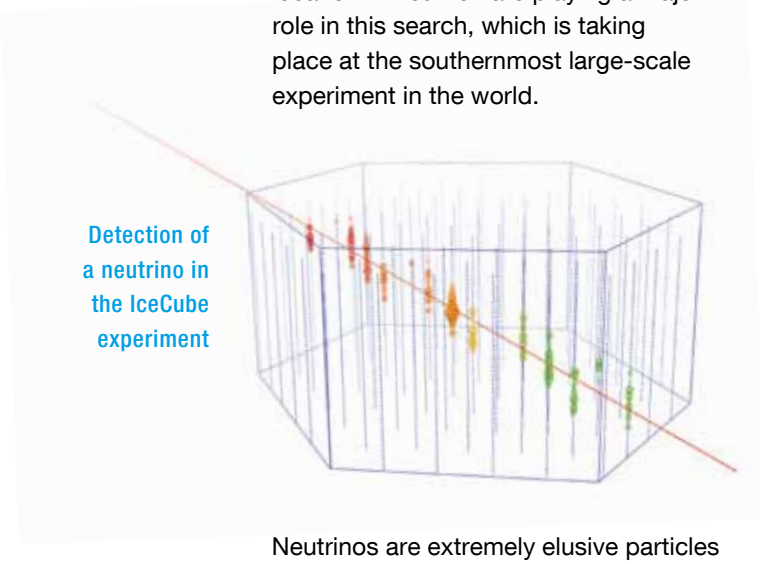
Windows on the universe

IceCube searches for neutrinos from space

"The experiments with cosmic neutrinos and gamma radiation give us exciting insights into the natural particle accelerators of the universe, which shed new light on the mysteries of cosmic radiation."

Prof. Christian Stegmann, Director of DESY in Zeuthen

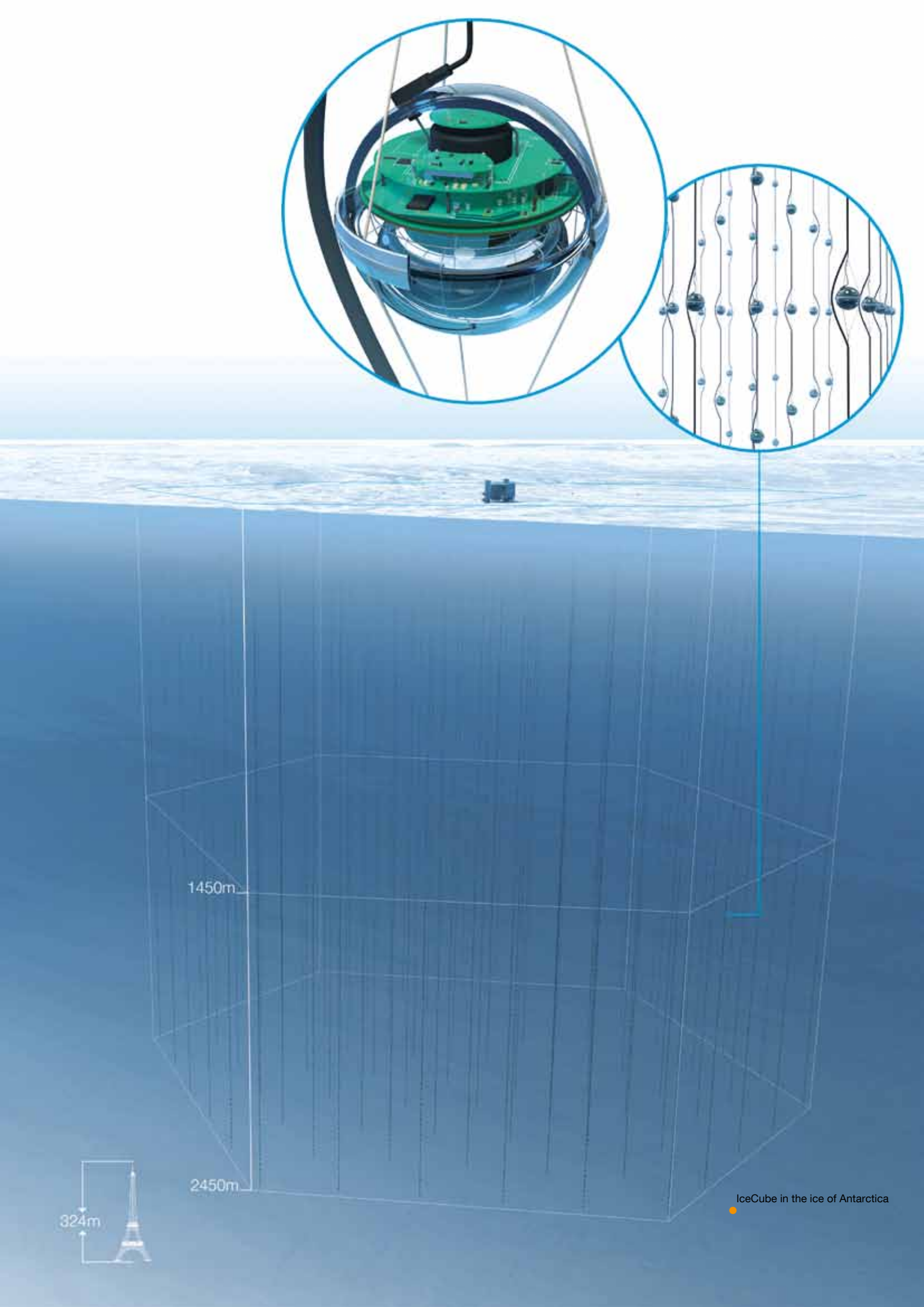
What happens near black holes? How does a supernova explode? And what is the origin of the inconceivably energetic particles that shower down on the Earth with cosmic radiation? Physicists hope to get answers to these questions from an unusual telescope in a spectacular location: the South Pole. Here, the sensors of "IceCube" are waiting for neutrinos from outer space – ghostly elementary particles produced by cataclysmic events in the far reaches of the universe. Physicists from the DESY location in Zeuthen are playing a major role in this search, which is taking place at the southernmost large-scale experiment in the world.



Detection of a neutrino in the IceCube experiment

Neutrinos are extremely elusive particles that hardly interact with matter at all. To catch sight of them despite this drawback, researchers have installed a huge, sophisticated camera in the ice cap of Antarctica. Eighty-six cables have been sunk thousands of metres deep in the ice, and hanging from each one are dozens of glass balls. These basketball-sized spheres act as "eyes" for light signals that the neutrinos sporadically generate in the crystal-clear ice. The more than 5000 light sensors make up a lattice about a cubic kilometre in size. It can measure the directions in which neutrinos are travelling, and from this, physicists can reconstruct which regions of space the elusive particles are coming from and where they originated. One scenario of interest might involve signals of a supernova currently exploding somewhere in our own galaxy. A celestial fireworks display of this kind would release an extremely large number of neutrinos that would doubtlessly be discernible with IceCube. Experts presume that a star would not be able to explode at all were it not for the neutrinos forcing the shell of the star outward with tremendous pressure. With IceCube, they hope to verify this theory and understand in detail how a star explodes.

In 2012, the researchers presented a very interesting result. They were keeping a lookout for neutrinos produced during gamma-ray bursts – tremendous eruptions of radiation in the far reaches of the universe. Surprisingly, IceCube did not detect a single neutrino matching an eruption of that sort. This result contradicts the hypothesis that gamma-ray bursts could act as "super-accelerators" for those extremely fast cosmic particles that occasionally strike the Earth's atmosphere. It appears that physicists may have to revise their current theories here.



IceCube in the ice of Antarctica

In search of black holes

The new gamma telescope CTA will measure cosmic events of great violence

"So far, we've identified about 150 high-energy gamma-ray sources in the sky; with CTA, we expect to discover ten times that many. That's well over a thousand more new sources!"

Dr. Stefan Schlenstedt, physicist at DESY in Zeuthen

Galaxies that resemble enormous whirlpools, or intergalactic clouds of dust shaped like a horse's head – the field of astronomy is known for spectacular images of this kind. But there are also telescopes that detect light outside the visible spectrum, such as gamma rays. Gamma radiation is produced during cosmic events of tremendous violence, such as supernova explosions. Now, plans have been made for a new observatory that will detect gamma rays with unprecedented sensitivity: the Cherenkov Telescope Array (CTA) gamma observatory. DESY is a major contributor to this large-scale international project.

Gamma rays are the most energetic electromagnetic waves known to science. A gamma quantum can contain many trillions of times more energy than a quantum of visible light. The processes during which this radiation is created in the universe are correspondingly violent. For instance, gamma rays are produced when particles of matter are accelerated to incredible energies in the vicinity of black holes, or when a neutron star rotates about its axis at mind-boggling speed. Special-purpose telescopes that detect gamma radiation can provide valuable details about these distant, formidable events.

The principle of the CTA gamma observatory is as follows: When high-energy gamma rays strike the atmosphere of the Earth, they trigger a cascade of particles. This, in turn, generates special flashes of blue light, called Cherenkov radiation. Multiple telescopes distributed over an area of several square kilometres pick up this light. The data can then be used to reconstruct where a gamma quantum came from and how much energy it contained.

Today's installations consist of at most five individual telescopes, but CTA is designed to have approximately 100. To keep the entire sky in view, two locations are planned: a smaller one in the northern hemisphere, and a larger one in the southern hemisphere at a site the size of 100 football fields.

The CTA team includes 1000 experts from 25 countries – a global consortium. "DESY makes up the biggest group among the 140 institutions involved in CTA," says DESY physicist Stefan Schlenstedt. Among other tasks, the DESY physicists are responsible for the construction of medium-sized telescopes, and they are playing a leading role in the development of the telescope control system.

DESY is taking part in a number of international research projects aiming to detect gamma radiation from cosmic sources, among them the H.E.S.S. telescopes in Namibia.

"With PETRA III and FLASH, we have two of the world's best X-ray sources for detailed studies of the structure and behaviour of matter." *Prof. Edgar Weckert, DESY Director in charge of Photon Science*

"For over 50 years, researchers at DESY have been developing innovative accelerator designs and technologies that consistently make it possible to break new scientific ground." *Dr. Reinhard Brinkmann, DESY Director of the Accelerator Division*

"DESY's particle physicists are searching for the basic building blocks of the universe as they work at the forefront of large-scale experiments around the world." *Prof. Joachim Mnich, DESY Director in charge of High-Energy Physics and Astroparticle Physics*

"DESY already plays a very prominent role in international astroparticle physics. We want to reinforce that role and expand the DESY location in Zeuthen into a national centre in this field." *Prof. Christian Stegmann, Director of the DESY location in Zeuthen*


Medicine
Nanotechnology
Microcosm
RESEARCH


METROPOLITAN REGION
RESEARCH
LARGE-SCALE FACILITIES
DESY
TRAINING
INNOVATION
COOPERATION

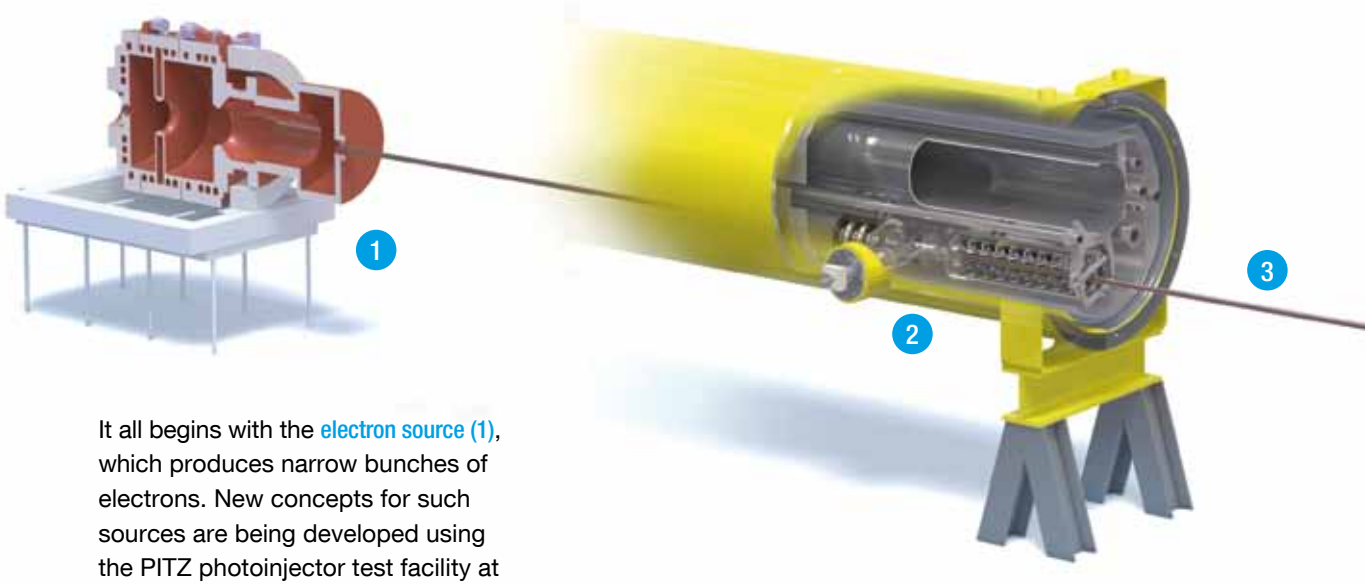
LARGE-SCALE FACILITIES FOR SCIENCE

Large-scale facilities make it possible to carry out top-level research and produce innovations. DESY's accelerators are super-microscopes that are in great demand internationally and can be used for a broad range of applications. Accelerators bring tiny charged particles to high energies and to speeds close to that of light. By causing the particles to collide head-on, particle physicists gain important insights into the nature of the fundamental building blocks of matter. Materials researchers, biologists and chemists, on the other hand, benefit from the extremely powerful and collimated X-ray radiation that the fast-moving particles emit. DESY's accelerators have a high reputation in both fields worldwide.

Three large accelerators dominate the DESY site today: PETRA III is the world's best storage ring when it comes to generating X-ray radiation; FLASH produces ultrashort pulses of "soft" X-ray radiation that make unique experiments possible; and beginning in 2015, the European XFEL will set a new world record by generating the most intensive X-ray flashes in history. This trio makes DESY the world's leading centre for X-ray experiments.

Accelerators as super-microscopes

How fast particles produce X-ray radiation



It all begins with the electron source (1), which produces narrow bunches of electrons. New concepts for such sources are being developed using the PITZ photoinjector test facility at the DESY location in Zeuthen.

When the particles leave the electron source, their energy is relatively low. The big energy boost is provided by the accelerator modules (2), into which powerful radio waves are fed. The electrons can “ride” these radio waves like surfers riding an ocean wave. Superconducting TESLA modules developed at DESY are particularly effective in this context.

The electrons fly through vacuum tubes (3) to ensure that they are not slowed down by air. Magnetic lenses make sure that the particle bunches always remain tightly bundled. If necessary, deflecting magnets are used to guide the electrons around the curves in the tubes.

Once the particles have reached their maximum energy, they are guided through magnetic structures known as undulators (4). These force the electrons along a slalom path and cause them to emit intense flashes of X-ray radiation.

Researchers use the flashes to study all kinds of samples at experimental stations (5). Basically, the atoms in the sample scatter the X-rays, which are then captured by detectors. Scientists use the measurement data to reconstruct how the atoms in the samples, e.g. biomolecules, are arranged – one of the necessary conditions for gaining a detailed understanding of a material’s properties.

Either a storage ring or a linear accelerator can be used to accelerate the particles. Inside a storage ring, electrons can circulate for hours and supply X-ray radiation to many different experimental stations. The number of experimental stations that can be used with a linear accelerator is lower. Such accelerators can, however, produce short, intense X-ray flashes that display the properties of laser light – a necessary condition for a new generation of experiments.


Gewicht:

PETRA III undulators

Brilliant storage ring PETRA III

The world's brightest storage ring opens up new possibilities for nanoresearch

PETRA was the world's biggest accelerator when it was commissioned in 1978. It was used initially as a "collider" for particle physics experiments; later it served as the pre-accelerator for the even larger HERA ring. Following that, it was converted into the most brilliant radiation source of its kind: since 2010, PETRA III has been supplying X-ray radiation that is more powerful and tightly focused than anything produced by other storage rings worldwide.

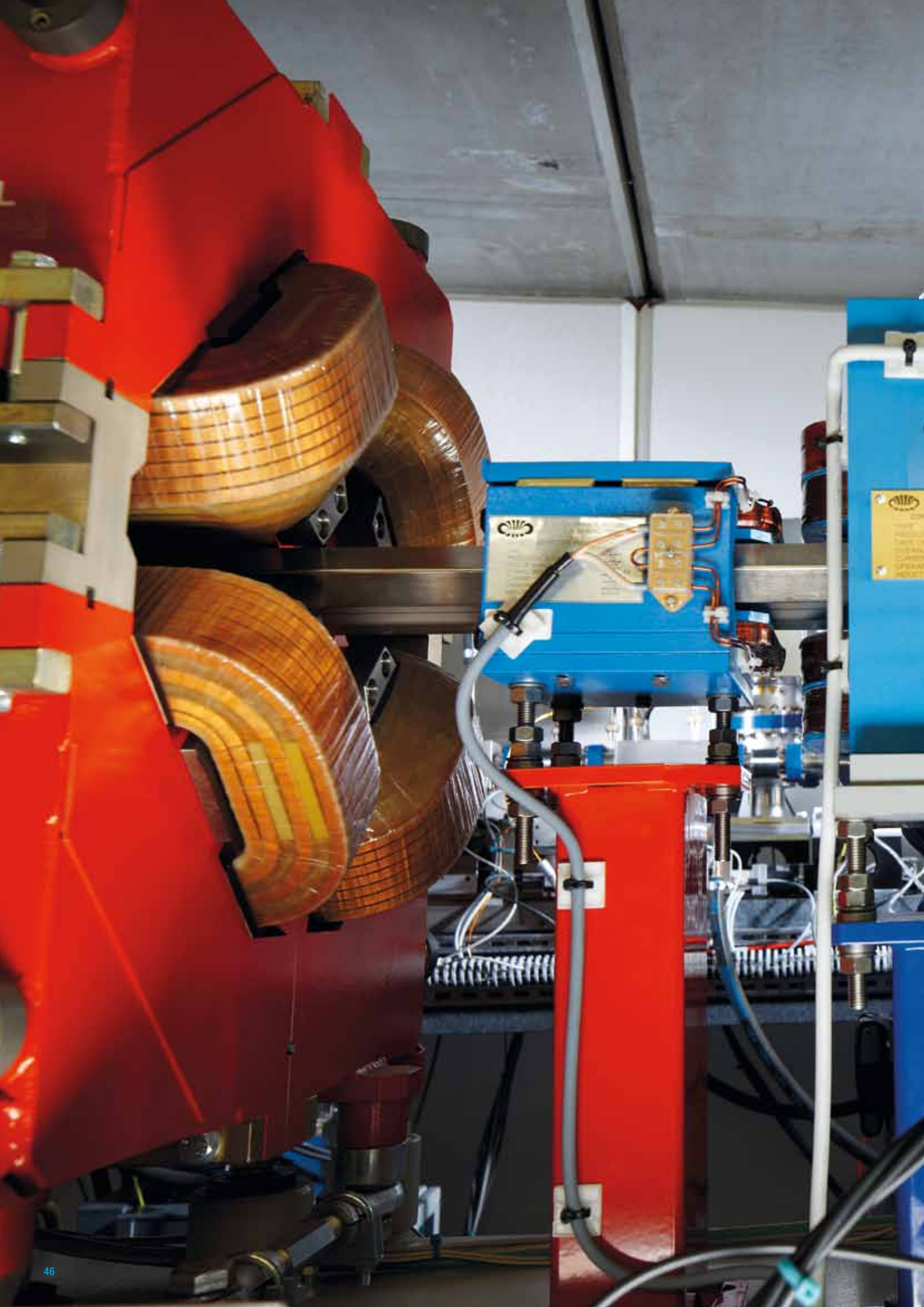
A total of 14 special magnets (undulators) generate the X-ray radiation. The X-rays travel through tubes to 30 experimental stations used by researchers to conduct experiments – 24 hours a day, seven days a week. The experimental hall is unusual: it is nearly 300 metres long, slightly curved and has a floor made of the longest concrete slab ever cast in a single piece. This slab shields the PETRA III measuring stations from disturbing vibrations – a feature essential for the high precision of the experiments.

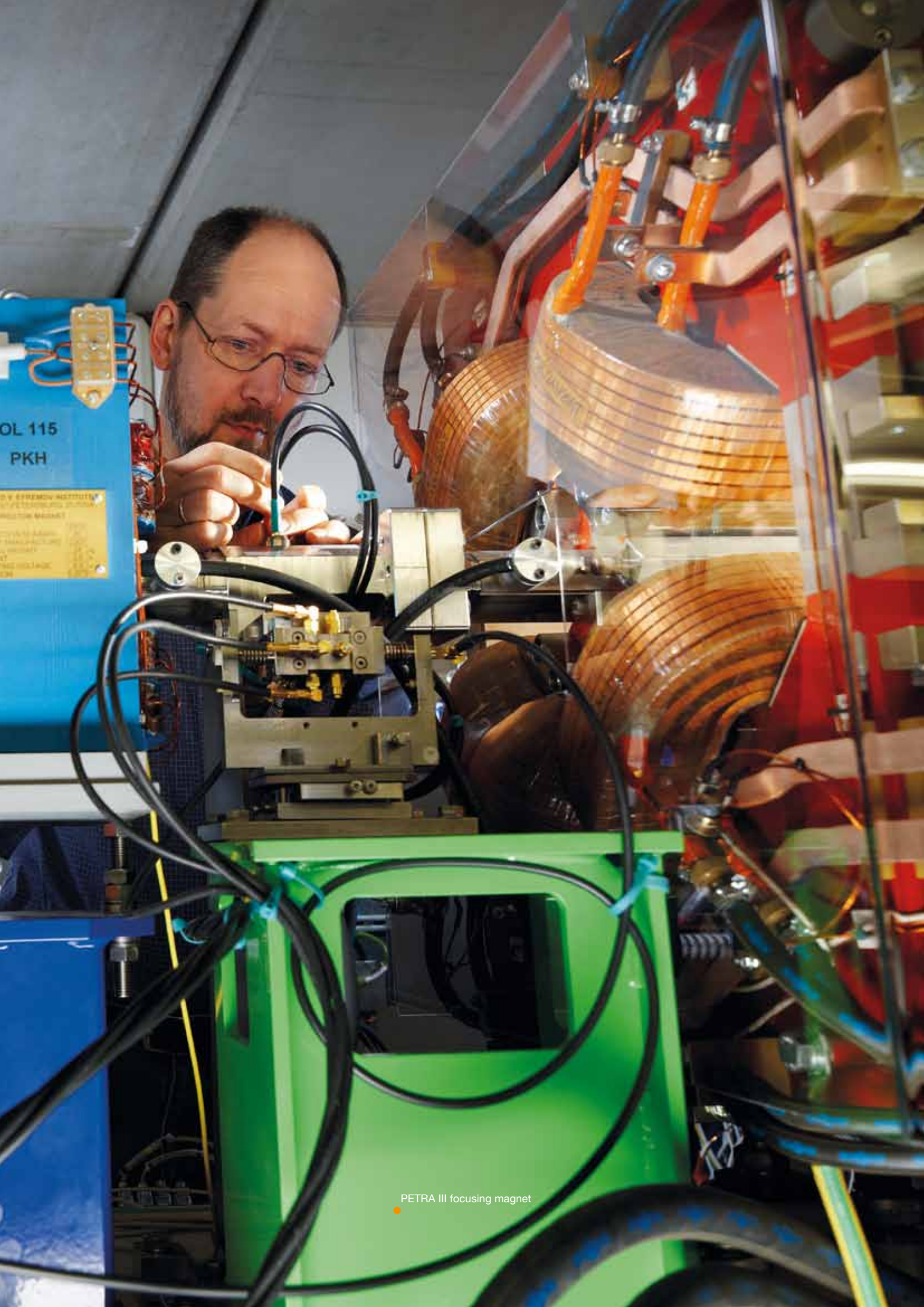
The special characteristic of PETRA III is the tightly collimated X-ray beams, which are up to 5000 times finer than a human hair. This makes it possible to study extremely small samples, such as tiny protein crystals or nanocrystals that will be used in the hard drives of the future. PETRA III can also generate very "hard" (i.e. short-wavelength) X-rays, which penetrate deeper into materials than other X-ray radiation. This is an important advantage when analysing new metal alloys such as those being developed for the automobiles and aircraft of tomorrow.

Experiments at PETRA III range from medical research to nanotechnology.

Researchers from around the world are extremely interested in PETRA III, which is why the facility is regularly over-booked and only a fraction of the experiment requests can be granted. That's one reason why the facility is being further expanded to include two new experimental halls with additional measuring stations that will be ready by 2014.

At the PETRA III experimental stations, extremely powerful and highly collimated X-ray radiation is available to scientists for their experiments.





PETRA III focusing magnet

Record X-ray pulses at FLASH

The vanguard of a new laser generation is located in Hamburg

For decades, scientists could only dream of a laser that would produce highly intense, ultrashort X-ray flashes. This vision is now a reality at DESY: since 2005, FLASH has been supplying high-intensity laser pulses consisting of "soft" (i.e. relatively long-wavelength) X-rays for research purposes. The 300-metre-long facility is not ring-shaped but completely straight. Its core component is a superconducting accelerator based on TESLA technology. This accelerator fires fast electrons through a special arrangement of magnets called an undulator, in which laser flashes are produced. This setup is known as a free-electron laser (FEL), and FLASH is the first FEL facility in the world to produce X-rays.

The ultrashort and highly intense X-ray pulses from FLASH make it possible to shoot films in the nanocosmos.

The FLASH X-ray bursts have special properties. They are a thousand times more powerful than the pulses emitted by comparable conventional lasers, and they are also much shorter than the X-ray pulses produced in a storage ring. This enables scientists to monitor extremely rapid processes in detail, and answer questions such as: What exactly happens during chemical reactions? What occurs when a metal melts? What happens when tiny nano-magnets – promising materials for the data storage units of the future – change their magnetization?

The international research community is tremendously interested in FLASH. However, not every scientist who would like to work with the intense X-ray flashes has the opportunity to do so, which is why the facility is being expanded. A second tunnel for undulators is being built branching off from the accelerator tunnel. The X-ray flashes from this tunnel will be guided into a new experimental hall with several measuring stations that offer plenty of space for additional experiments.

The mobile cleanroom (left) – a dust-free environment – is used to assemble components for the FLASH experiments in the large experimental hall (right).

Accelerator modules in the FLASH tunnel


MODUL 6

A superlative X-ray laser

The European XFEL – a unique research facility – will go into operation in 2015

In 2015, a spectacular laser facility will begin producing X-ray flashes that are shorter than a trillionth of a second and billions of times brighter than the radiation generated in storage rings. The European XFEL is a gigantic 3.4-kilometre-long laser facility located in underground tunnels. It runs in a north-westerly direction from the DESY site in Hamburg-Bahrenfeld to a large experimental hall located in the German federal state of Schleswig-Holstein.

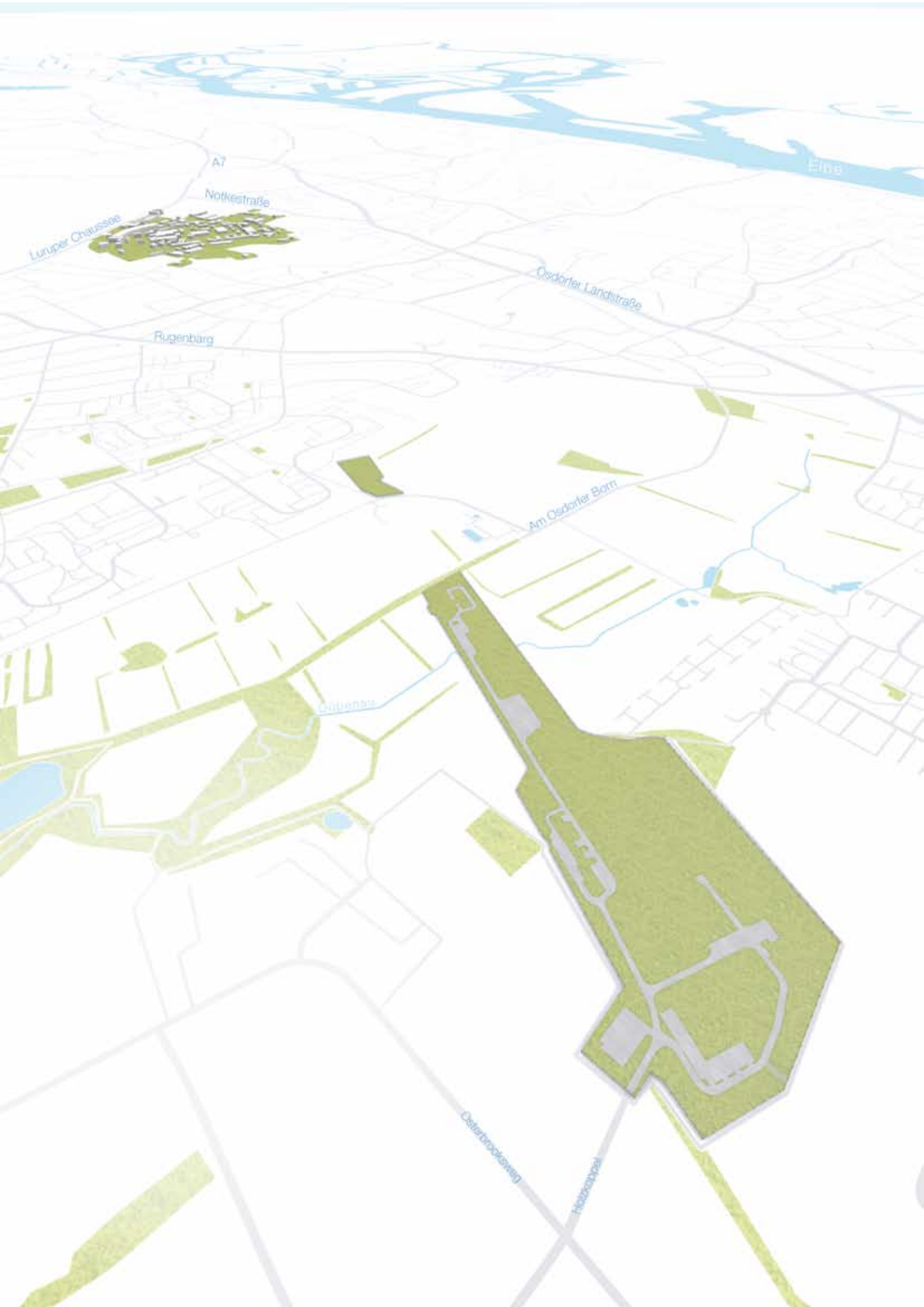
The European XFEL will generate 27 000 X-ray flashes per second and open up completely new research opportunities to natural scientists and industrial companies.

The core component of the European XFEL is a superconducting accelerator just under two kilometres long, which brings electrons to nearly the speed of light and then sends them through long undulators. These special magnets force the electrons along slalom paths, which causes the particles to emit extremely short and powerful X-ray flashes. Unlike the X-ray pulses sent out from a storage ring, these flashes have laser properties – a precondition for certain experiments, such as recording holograms.

There are X-ray lasers of a similar size in Japan and the USA. However, unlike the European XFEL, these do not use superconducting accelerators and therefore produce relatively few X-ray flashes per second. The European XFEL, on the other hand, generates 27 000 flashes per second, which offers a decisive advantage in various experiments.

Altogether, 12 countries are participating in the European XFEL project. DESY, the main shareholder, is working closely with the company European XFEL GmbH on the construction and operation of the facility. Among other things, DESY and international partners are building the heart of the X-ray laser facility – the 1.7-kilometre super-conducting accelerator including the electron source. DESY will also operate the accelerator after the facility is commissioned. The research possibilities offered by the European XFEL will benefit scientists from various disciplines – from semiconductor physicists to molecular biologists, medical scientists, chemists, astro-physicists and geologists.

The future experimental hall and one of the tunnels for the European XFEL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Lingener Chaussee
Osdorfer Landstraße
Rugenberg
Am Osdorfer Born
Ostarbrookweg
Hobbenbrook

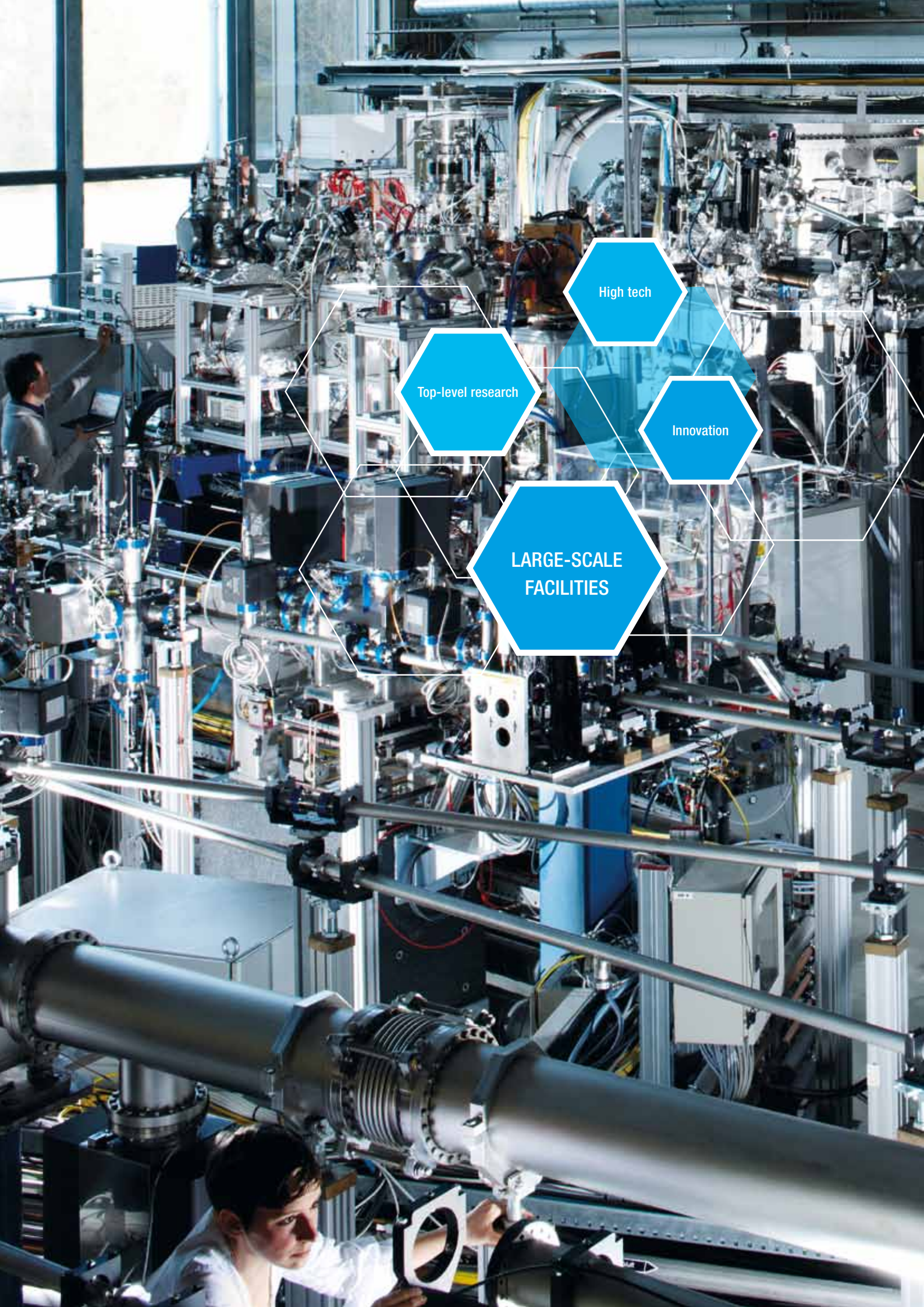
"DESY is playing a pioneering international role in the design, construction and operation of particle accelerators. DESY's accelerator facilities attract outstanding scientists from around the world. They are also ideal instruments for training up-and-coming scientists." *Dr. Reinhard Brinkmann, DESY Director of the Accelerator Division*

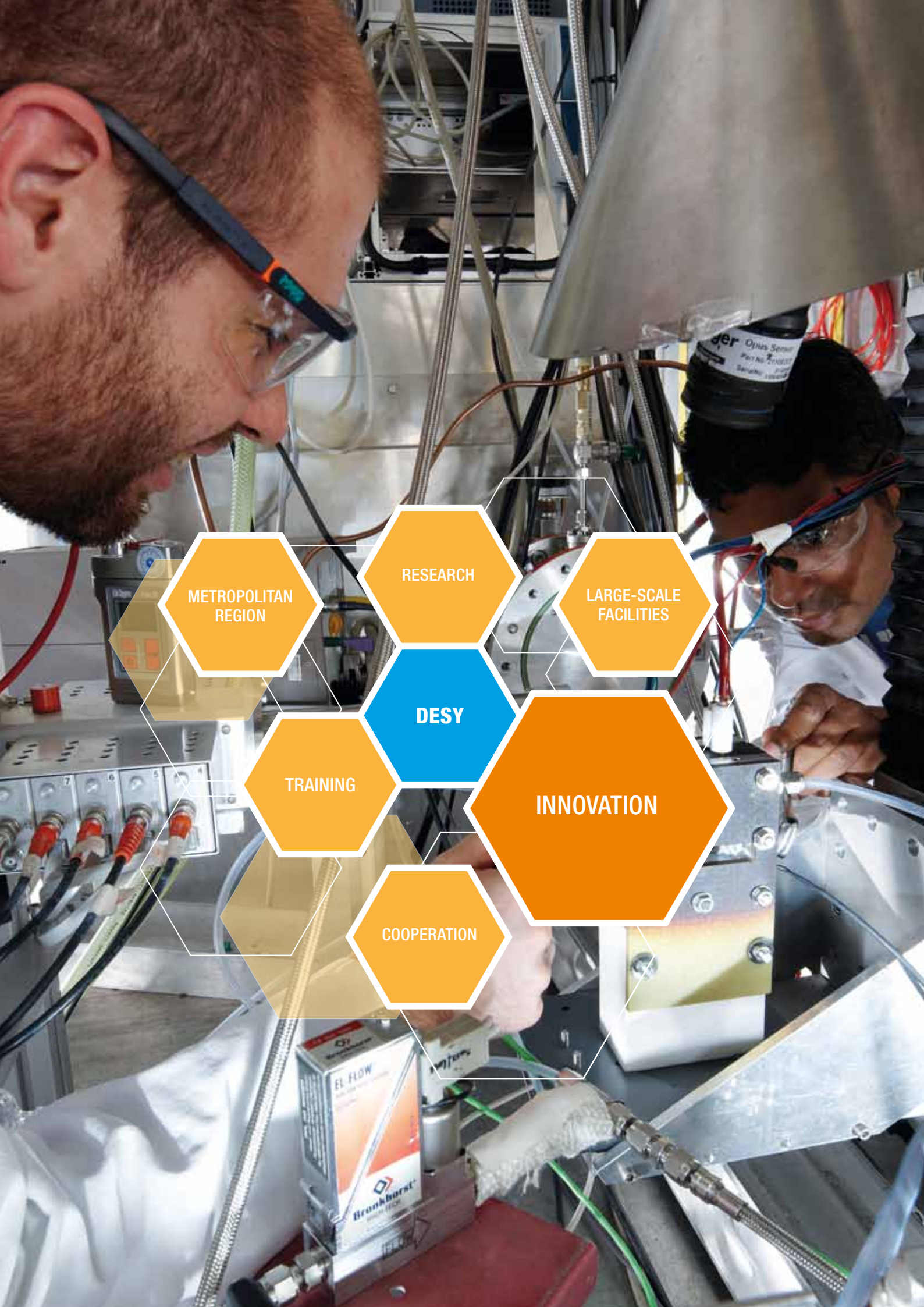
"Our technology developments are also driving activities in interesting business sectors. This benefits our partners in industry and other areas of the economy. The applications of the DESY accelerators include technologies for faster computers, better data storage systems, more efficient solar cells and batteries as well as high-tech materials and customized medications." *Christian Scherf, DESY Director of Administration*

"DESY is the most important partner involved in the European XFEL X-ray laser. Without DESY's expertise, it would be impossible to build this giant facility." *Prof. Massimo Altarelli, European XFEL Managing Director*

"In an effort to provide answers to the major urgent questions faced by the economy, science and society, the Helmholtz Association is using scientific research infrastructures such as DESY's large-scale facilities to investigate highly complex systems." *Prof. Jürgen Mlynek, President of the Helmholtz Association*

"Many clever minds must pursue a common goal and pool their skills to successfully build and operate large-scale facilities. Hundreds of experts strive to keep the DESY infrastructure highly reliable. Without their commitment, the most sophisticated accelerator wouldn't work." *Dr. Karsten Wurr, Head of Administration at DESY*


High tech
Top-level research
Innovation
LARGE-SCALE FACILITIES


METROPOLITAN REGION
RESEARCH
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DESY
TRAINING
INNOVATION
COOPERATION

INNOVATIONS FOR SOCIETY

Our economy depends on innovations. Without inventions and catchy ideas, new and commercially successful products would be inconceivable in our technology-oriented society. DESY contributes to this innovation process in a diversity of ways. On the one hand, knowledge derived from basic research provides a broad, fertile ground for future innovations. On the other hand, some experiments are directly related to applications – for example, when industrial firms book measurement time on DESY's X-ray sources to conduct advanced product development. Furthermore, there are the spin-offs that evolve from some research projects, such as the accelerator and detector technologies developed at DESY that can also be applied to innovative medical high-tech equipment. These technologies hold the promise of more accurate diagnoses and more readily tolerated therapies, for instance in cancer treatment.

An important aspect is DESY's cooperation with firms that are helping to develop its accelerators and detectors. One example is the construction of the superconducting TESLA accelerator modules. DESY generates know-how among the participating high-tech firms. The companies benefit from the cooperation by coming up with new production processes, for example, as the components and processes they develop for DESY require absolute cutting-edge technology and sometimes entirely new technical solutions. The latter can subsequently become useful for manufacturing other products, for instance in the medical industry, in radar and satellite technology and in chemical engineering. As a result, it's not uncommon for DESY's industrial partners to gain a technological advantage over their competitors.

Mini-detectors for medical use

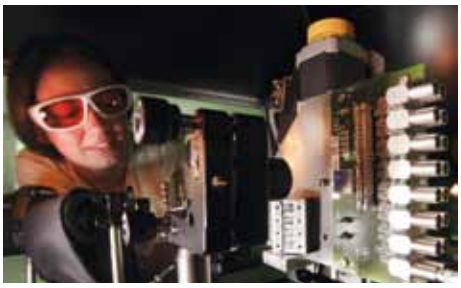
DESY technology for the doctor's practice

Italian physicist Erika Garutti's job is to develop highly sensitive sensors for particle detectors used in basic research. One day, she realized that this technology could be just as useful in a medical diagnostic system, the PET scanner. This bright idea evolved into a successful European research project conducted by DESY and CERN in conjunction with three medical centres.

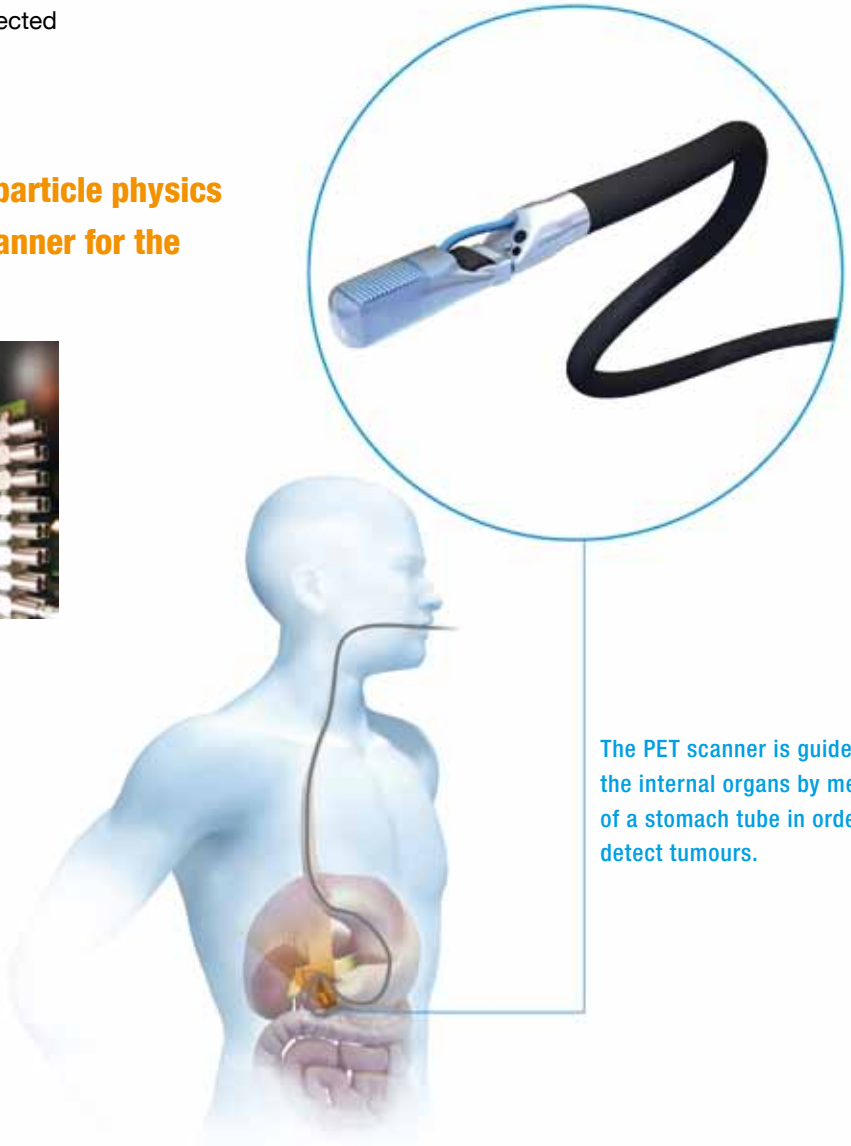
One application of PET scanners is the early diagnosis of tumours. The physician gives the patient a dose of a sugar compound labelled with a weakly radioactive substance. In the body, the sugar is preferentially absorbed by cancer cells. As the radio-active substance decays, it emits high-energy light flashes that are detected by special sensors. The resulting signals are converted by a computer into images that reveal to the physician whether and where there are tumour cells.

"With our new sensors, it should be possible to obtain PET images of a substantially higher resolution," Garutti explains. "And the radiation dose to the patient could be significantly reduced." The scientists have already created a prototype which proves that the sensors work the way they're supposed to. Now the researchers are working on a miniature detector to be used at the tip of a stomach tube to detect dangerous pancreatic tumours as early as possible. Clinical trials are scheduled to begin in 2014.

Ideas and know-how from particle physics led to a new type of PET scanner for the early detection of cancer.



Test setup for the development of the PET scanner



The PET scanner is guided to the internal organs by means of a stomach tube in order to detect tumours.

Reduced radiation doses in X-ray examinations

A team of researchers at DESY develops lower-dose technology

In Germany, breast cancer is the most common form of malignant tumours in women. That's why experts recommend mammography as a preventive measure. Ideally, X-ray examinations should take place at regular intervals starting at the age of 50. But X-ray examinations are of course associated with radiation exposure. That's why DESY researchers are collaborating with the Helmholtz Zentrum München and the University of Hamburg to develop a substantially lower-dose method.

Plasma accelerators could substantially lower the radiation dose in mammography.

The X-rays used to examine patients are presently generated by X-ray tubes, which emit a relatively broad spectrum of radiation. Much of that radiation is not required for the X-ray images, but it nevertheless contributes to the absorbed dose and consequently to the radiation exposure of the patient.

The team of researchers therefore intends to replace X-ray tubes with another, more efficient radiation source, based on a laser whose strong flashes of light generate a plasma. This plasma is electrically charged and can accelerate electrons sufficiently to make them emit X-rays when they pass through a magnetic field.

Most importantly, such a plasma accelerator would generate a substantially narrower spectrum than an X-ray tube. This means more useful and less wasted radiation. Simulations suggest that by taking advantage of other special characteristics, it would be possible to reduce the radiation dose to one third of the current level. The project is now being launched. Philips Healthcare is one of the principal industrial partners that are already showing an interest in this new technology.

X-ray imaging of the breast allows early tumour detection but is always associated with radiation exposure.

Strong partners in materials research

The Helmholtz-Zentrum Geesthacht investigates industrial materials at DESY

"The excellent properties of the PETRA III X-ray source enable us to use innovative approaches when it comes to developing new materials."

Prof. Wolfgang Kaysser, Scientific Director of the Helmholtz-Zentrum Geesthacht

The high-strength aluminium fuselage of a passenger jet, corrosion-resistant steels for ship propellers, heat-resistant turbine blades – all of these high-tech materials have one thing in common: materials scientists need to know as much as possible about their "inner life" to customize them for their intended applications. How are the atoms arranged within the materials? Do the materials contain harmful cracks, pores or foreign bodies? Valuable answers to such questions can be obtained with PETRA III, one of the world's brightest X-ray sources. That's why the Helmholtz-Zentrum Geesthacht maintains an outstation at DESY as part of its German Engineering Materials Science Centre (GEMS).

The outstation, which consists of several measuring stations in the PETRA III experimental hall, is focused on the engineering science aspects of materials research. For example, scientists can use the X-ray beams to investigate in detail what happens at the nanoscale when a welding seam is formed.

The materials experts can also produce precise X-ray images of massive workpieces such as a complete ship's propeller, or analyse plastic membranes that may someday help to sequester carbon dioxide. In this way, the experts at PETRA III are playing a role in the advanced development of materials and processes that will sooner or later become commonplace in industrial, transportation and everyday applications – including new materials for lighter-weight cars, more effective manufacturing methods for aircraft construction and improved hydrogen tanks for environmentally compatible drive systems.

Materials research at PETRA III: At the Imaging Beamline (IBL), materials experts can obtain detailed images with exceptionally high resolution.

Material test of an engine block

Kick for the cat

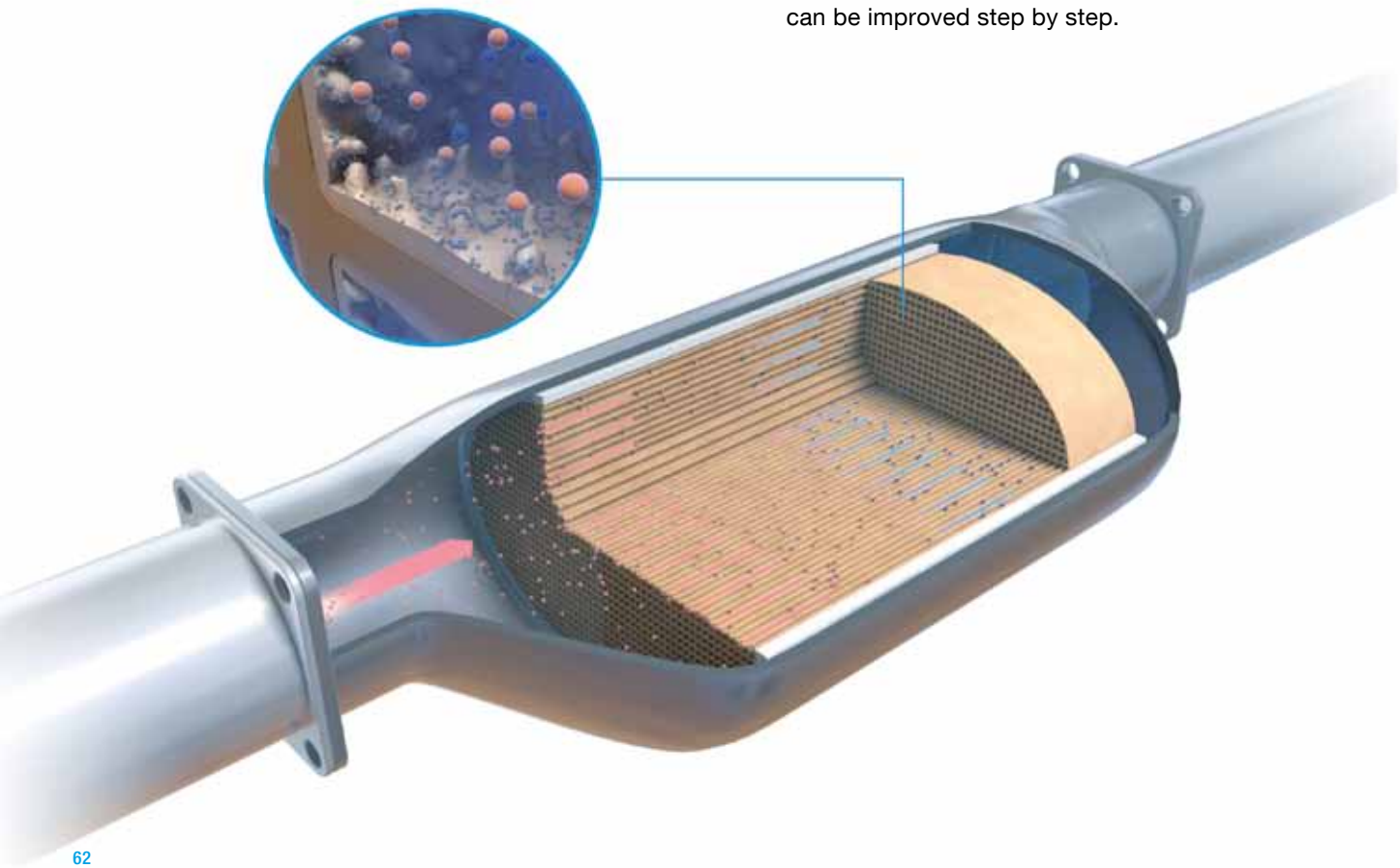
How industrial firms benefit from DESY

The X-ray flashes generated by accelerators are highly intense and tightly collimated. They are thus ideally suited for the X-ray imaging of various substances, including materials, proteins and chemical catalysts. For years DESY's infrastructure, which is unparalleled in Germany, has also been used by industrial clients. Some carry out individual projects, while others rent an annual amount of measurement time at a fixed rate. The experiments at DESY help such companies make their products more efficient and more durable.

Beiersdorf AG is analysing the basic properties of substances that are important ingredients of cosmetics.

DESY's X-ray microscopes reveal ways of making the diesel catalytic converter more efficient and more durable.

Other companies are investigating catalysts – substances that speed up a chemical reaction to make it useful in practice. These catalysts serve a variety of purposes. For example, Haldor Topsøe from Denmark is developing reaction accelerators for the chemical industry. The French organization IFPEN is investigating catalysts for the desulphurization of petroleum and natural gas for the petrochemical industry. And Umicore from Hanau, Germany, has focused on the most well-known application of catalysts – the exhaust gas catalytic converter in the automobile. The "cat's" functions include the conversion of highly toxic carbon monoxide into carbon dioxide. The experts used DESY's X-ray sources to learn precisely how that happens. To study aging effects, they compared used diesel cats with brand-new ones and discovered distinct differences in atomic structure between the old and the new. Thanks to such basic research findings, exhaust catalytic converters can be improved step by step.



Fuel cells in X-ray light

Experts are optimizing environmentally friendly technologies of the future

“We’re investigating fuel cells under realistic conditions so that industrial users may benefit from our results.”

Dr. Christina Roth, materials scientist

Fuel cells promise to become the automotive power sources of the future. They convert hydrogen or methanol into electric current efficiently and without environmental harm, and may someday endow electric cars with longer ranges. Materials researchers at Technische Universität Darmstadt are studying fuel cells using high-intensity X-rays from the accelerator. Their findings give manufacturers indications on how to develop improved, more effective fuel cells.

The researchers bring complete, intact fuel cells to Hamburg to examine them in detail with X-rays. “We’re particularly interested in the electrodes,” says materials scientist Christina Roth. “That’s where the essential reactions occur.” Among other processes, a platinum catalyst ensures that hydrogen and oxygen molecules are split into atoms. These atoms then react to form water, a process that releases energy in the form of electric current.

But platinum tends to age during sustained operation. The minuscule platinum nanoparticles agglomerate into larger clumps, reducing the effectiveness of the catalyst. The finely collimated X-rays enable the researchers to observe what is happening on the surface of the platinum particles – for instance, how an oxygen molecule is adsorbed by the platinum and split into atoms. “Very few research teams in the world are capable of carrying out such measurements,” Roth says. The experts can also identify locations in the fuel cell where the aging process is especially fast – which is of fundamental importance for manufacturers striving to develop systems with a longer service life.

At DESY, fuel cells are examined with high-intensity X-rays from the accelerator.

Research as an innovation driver

DESY cooperates with commerce and industry

"We cooperate closely with industrial companies, and we actively support the transfer of technologies and know-how."

Katja Kroschewski, Head of Technology Transfer at DESY

Particle accelerators are highly complex and replete with innovative technology that can't simply be ordered from a catalogue. That's why the DESY experts must develop many components themselves through pioneering work in which they collaborate closely with industrial partners. The resulting synergy benefits both sides. Without industry, DESY would not be able to build the systems. DESY's business partners, for their part, develop new technologies and processes which they can subsequently transfer to other business segments – such as electronics or radio-frequency applications, vacuum and refrigeration technologies or superconducting systems. Some of these developments result in patent applications.

A gas monitor detector developed at DESY, for example, accurately records the position and intensity of the X-ray flashes generated by accelerators such as FLASH. As yet, no comparable system exists on the market anywhere else in the world. The patent is currently being implemented in an accelerator in the USA. It could also be of interest to the semiconductor industry.

A radiation dosimetry system invented in Hamburg monitors whether there is excessive radiation exposure in an accelerator facility. This patent could be useful in medical accelerator facilities, among others. In the development process, DESY has collaborated with two commercial firms and concluded licensing and marketing agreements.

In conjunction with industrial companies, DESY has developed a new manufacturing process for seamless niobium resonators used in superconducting accelerator modules. Their advantages over welded resonators include lower production costs, reduced material consumption and a more homogeneous structure. In a joint undertaking with a Chinese firm, a manufacturing process was developed for making sheet metal of high-purity niobium, the basic material for high-performance accelerators.

To be able to measure and control the extremely short electron bunches within accelerators, DESY is developing an innovative system using ultrafast electronic components. Because of its flexible design, this system is not only useful in accelerators but also in medical technology, aircraft manufacturing, industrial online inspection, mobile-phone manufacturing and precision metrology.

The DESY Technology Transfer department serves as the interface between science and commerce. It provides support during the transition from laboratory result to commercial application, and assists scientists as well as industrial partners in the commercialization of new technology.

Quality test of a resonator

Upgrade for the LHC

DESY experts are working on the future of the super-accelerator

Since 2010, the LHC at the CERN research centre in Geneva has been churning out data. The facility accelerates protons to collide with enormous force, causing new elementary particles, such as the Higgs boson, to be created. The more protons collide within the accelerator ring, the more data the LHC produces, and the more thoroughly the generated particles can be investigated. That's why CERN is planning an expansion of the accelerator around 2020. The expanded machine is expected to produce up to ten times more proton collisions than the present LCH can – an ambitious goal. That change will also require an upgrade of the particle "cameras", the detectors. DESY contributes to the preparations for this upgrade.

"DESY's know-how is in great demand in the LHC experiments."

Dr. Günter Eckerlin, particle physicist at DESY

"We'll completely replace the inside of the CMS detector," explains DESY physicist Günter Eckerlin. "The new sensors will be made of state-of-the-art materials to make them more robust, lighter and more sensitive." The problem is that the more collisions occur within the particle detector, the more its sensors are subjected to high-energy radiation. Ordinary chips like the ones used in a cell phone camera would fail very soon. That's why DESY researchers in conjunction with industrial scientists are searching for new, extremely robust sensor materials. Candidate materials are being tested, among other locations, at DESY in Hamburg and Zeuthen.

Radiation resistance is not the only attribute sought in the new sensors – they also need to be finer grained. "In the same way that digital cameras are providing more and more megapixels, we aim to substantially increase the resolution of our sensors," says Ingrid-Maria Gregor, who is in charge of the ATLAS detector upgrade at DESY. In doing so, the researchers are benefiting from the continuing advances in chip manufacturing technology. In collaboration with several universities, DESY is slated to assemble one of the end caps of ATLAS. This will involve more than 3000 individual modules with a total of 25 square metres of silicon. "DESY has abundant know-how in the design and operation of detectors," Eckerlin emphasizes. "There is a great demand for this expertise in the LHC experiments."

Smart storage

DESY scientists are developing sophisticated data management software

The LHC produces immense volumes of data. A single year's data would fill more than a million DVDs. To manage this data torrent, information scientists use a new computer concept: the Grid, a variety of distributed computing. In this system, dozens of computing centres around the globe interact synergistically. Simply stated, the Grid performs computation at the location where the computers happen to have available capacity at any given time. As a case in point, a physicist wishing to evaluate LHC data in Hamburg might receive the results – without being aware of it – from computers in France, Taiwan or the USA.

DESY scientists are participating in the continual expansion of the Grid. Their specialty is the organization of the data storage. That's a major challenge, because the storage resources on the Grid must not only receive and record vast data volumes reliably but also make them accessible from anywhere on Earth. "dCache" is a software package developed mainly by DESY – sophisticated technology for managing large data volumes. For example, the user simply needs to mark whether data is to be stored only on hard drive or on tape as well, and dCache will automatically take care of it. The user doesn't have to bother with the details.

dCache also saves money. Since the software stores several copies of a file at different locations, the required hardware can be less costly and potentially less reliable. If a storage medium should fail, the system will know exactly where else the file can be found.

If DVDs containing a single year's LHC data were stacked on top of one another, they would form a tower taller than Mount Everest.

At present, about half of all LHC data are stored on one of the 60 dCache systems around the globe. DESY is developing the software in conjunction with international partners, especially the Fermilab research centre in the USA and the Nordic Data Grid Facility (NDGF). dCache is an open source software program. Anyone can download it to use it for desired applications and to further develop it under a license. dCache is now also used in fields other than particle physics, for instance at the European radio telescope LOFAR. Keen interest is also evident among commercial companies.

The DESY computing centre is an important hub for the data analysis of the LHC experiments.

"Top-flight large-scale facilities and an inspiring research environment are the best setting for developing new ideas for key technologies and for successfully implementing them in products and processes." *Prof. Helmut Dosch, Chairman of the DESY Board of Directors*

"A strong economy also needs strong research institutions such as DESY. We must pool our knowledge and continue to foster closer liaison between commerce and research." *Dr. Georg Mecke, Site Director at Airbus Hamburg*

"Scientists from diverse disciplines rub elbows daily on the DESY campus. It's an ideal breeding ground for ideas that range far beyond any scientific specialities." *Prof. Robin Santra, Head of the Theory Division of the Center for Free-Electron Laser Science (CFEL)*

"Particle physics combines fundamental theories, new ideas and innovative technologies. Our research results are eventually used as spin-offs in many different everyday applications." *Prof. Erika Garutti, University of Hamburg*


Products
Solutions
Spin-offs
INNOVATION
Know-how

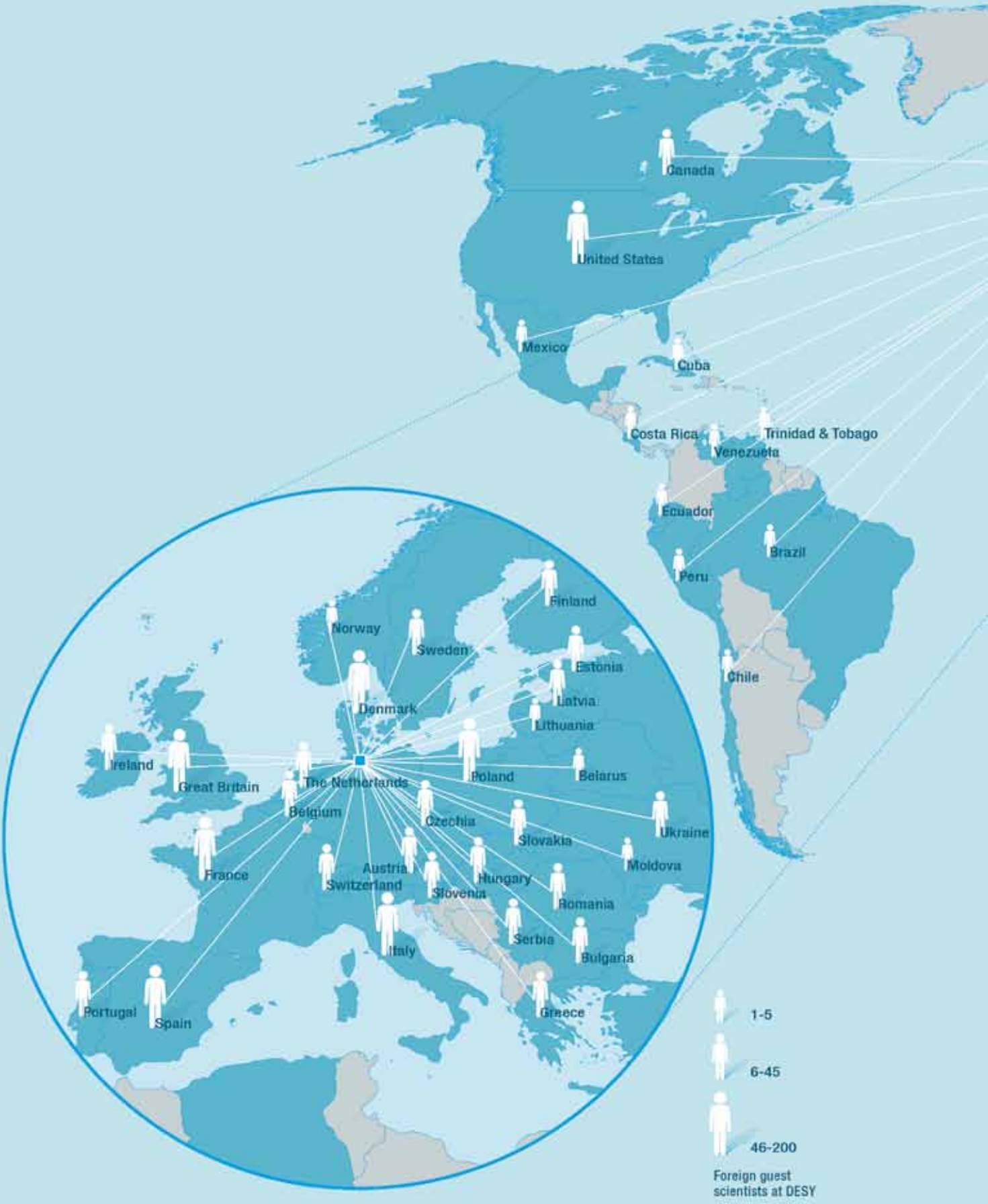

METROPOLITAN REGION
RESEARCH
LARGE-SCALE FACILITIES
DESY
TRAINING
INNOVATION
COOPERATION

A STRONG COOPERATION PARTNER

Top-level research is scarcely possible today without networking and cooperation among various institutes, countries and scientific disciplines. DESY too operates within strong networks. Each year, the research centre's unique facilities draw more than 3000 guest scientists from over 40 countries to Hamburg. To work as closely as possible with DESY, more and more institutions are establishing outstations on the campus itself. The collaboration with universities is especially intense. In 2011, DESY and the University of Hamburg expanded their cooperation even more and established the strategic partnership PIER.

Particle physics at DESY has always occupied a well-established position on the international research scene. Experts from around the world took part in the experiments at the storage ring HERA. Today, DESY physicists are playing leadership roles in all of the most important projects in particle physics.

The development of innovative accelerator technology is also taking place within collaborative efforts – whether in the Helmholtz Association's accelerator initiative ARD or in the international consortium that is developing the TESLA technology for the accelerators of the future. Cooperation on X-ray sources is equally intense. DESY has a share of more than 50 per cent in the X-ray laser European XFEL. Countries such as India, Sweden and Russia are involved in PETRA III. And a number of institutions that are closely connected with DESY are being set up on the campus in Hamburg: CFEL is devoted to research into ultrafast physical processes; CSSB will deal with infection research; and the Max Planck Society, which is already involved in CFEL, is planning the construction of a new institute.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Bulgaria
Portugal
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Foreign guest scientists at DESY

Network of knowledge

DESY is a magnet for researchers from around the world. Every year, more than 3000 guest scientists come to Hamburg and Zeuthen to conduct experiments at the DESY facilities.

Centre of excellence CFEL

The Center for Free-Electron Laser Science is investigating ultrafast processes

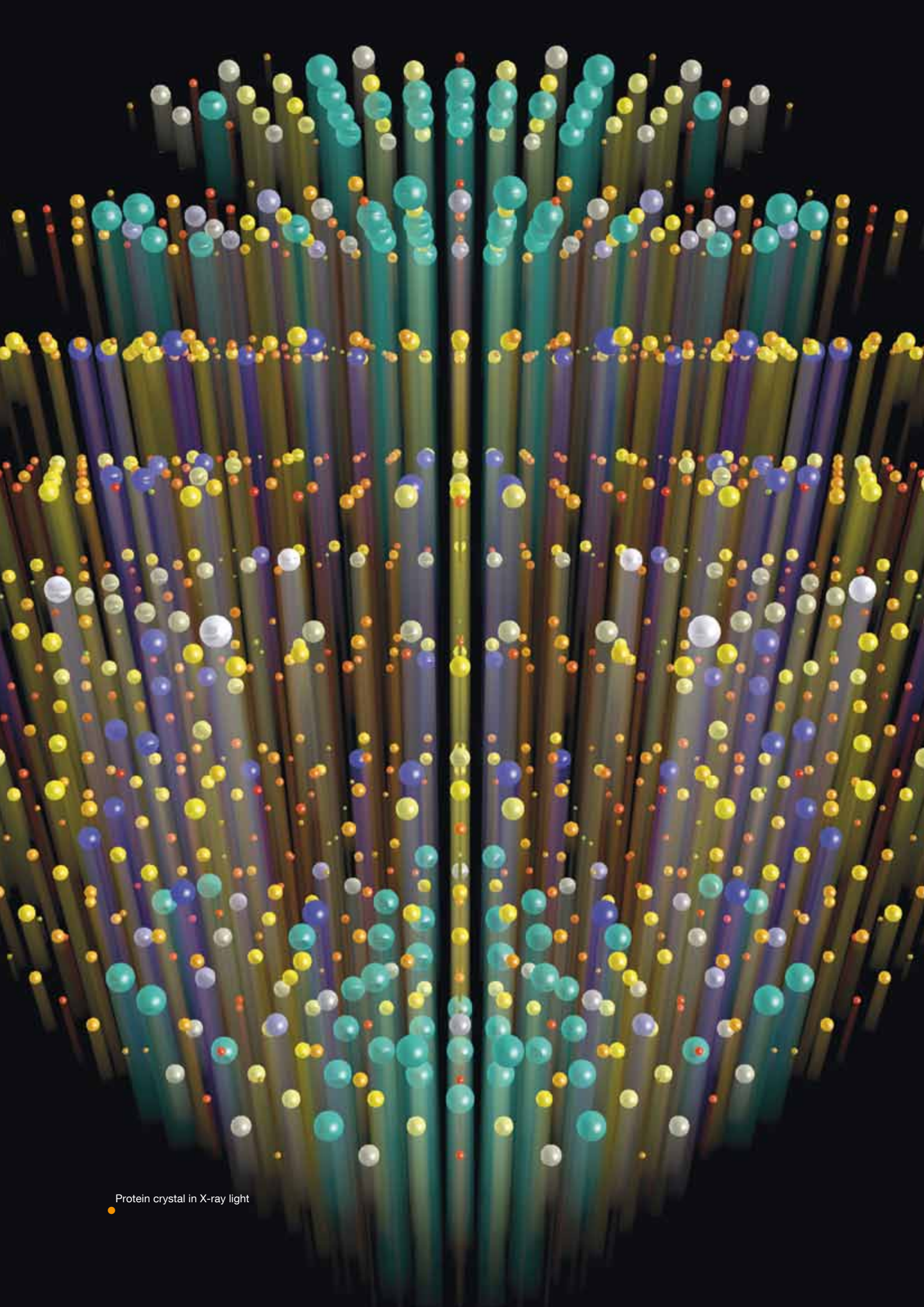
"DESY is the ideal home for CFEL. There is nowhere else in the world that brings together cutting-edge X-ray sources, interdisciplinary science and an environment for exciting collaborative research."

Prof. Henry Chapman, Center for Free-Electron Laser Science CFEL

Is it possible to observe how an electron jumps from one reactant to another with incredible speed during a chemical reaction? Can biomolecules be illuminated with intense X-ray flashes in such a way that scientists can discern the atoms they are made of? And is it possible to turn superconductors – materials that transport electric current without losses – on and off with pulses of light? It's been only a few years since scientists have had the capacity to address these questions. They are doing so with lasers and accelerators that generate ultrashort flashes of light and with special-purpose microscopes that can analyse nanoparticles with high precision.

In Hamburg, a relatively new centre is concentrating on this cutting-edge field of research. The Center for Free-Electron Laser Science (CFEL), a cooperation involving DESY, the Max Planck Society and the University of Hamburg, was established in 2007. The special feature of the centre is that CFEL experts are studying the tremendously fast processes in the nanocosmos from a variety of perspectives – in other words, with various research instruments. Some groups use the ultrashort X-ray pulses produced by FLASH, by the LCLS X-ray laser in the USA, or – in the future – by the European XFEL in Hamburg. Other teams are working with optical lasers or using electron or scanning tunnelling microscopes.

The results are correspondingly diverse. For example, CFEL physicists provided new insights into the behaviour of ceramic superconductors – a promising class of materials for power engineering. Other experts successfully carried out seminal experiments that make it easier to study membrane proteins. These proteins play a key role in the communication between somatic cells, for example. CFEL researchers were also involved in a spectacular advance in nanotechnology: the construction of the world's smallest storage bit to date, which consists of a mere twelve atoms. In the future, the Max Planck Society in particular would like to expand its activities and establish a new institute in Hamburg that is closely linked with CFEL.



Protein crystal in X-ray light

Infection research at CSSB

Researchers from different fields work together at the Centre for Structural Systems Biology

"We're now making even better use of the synergies of various fields of research. Like a lighthouse, CSSB will make our research visible near and far, even beyond national borders."

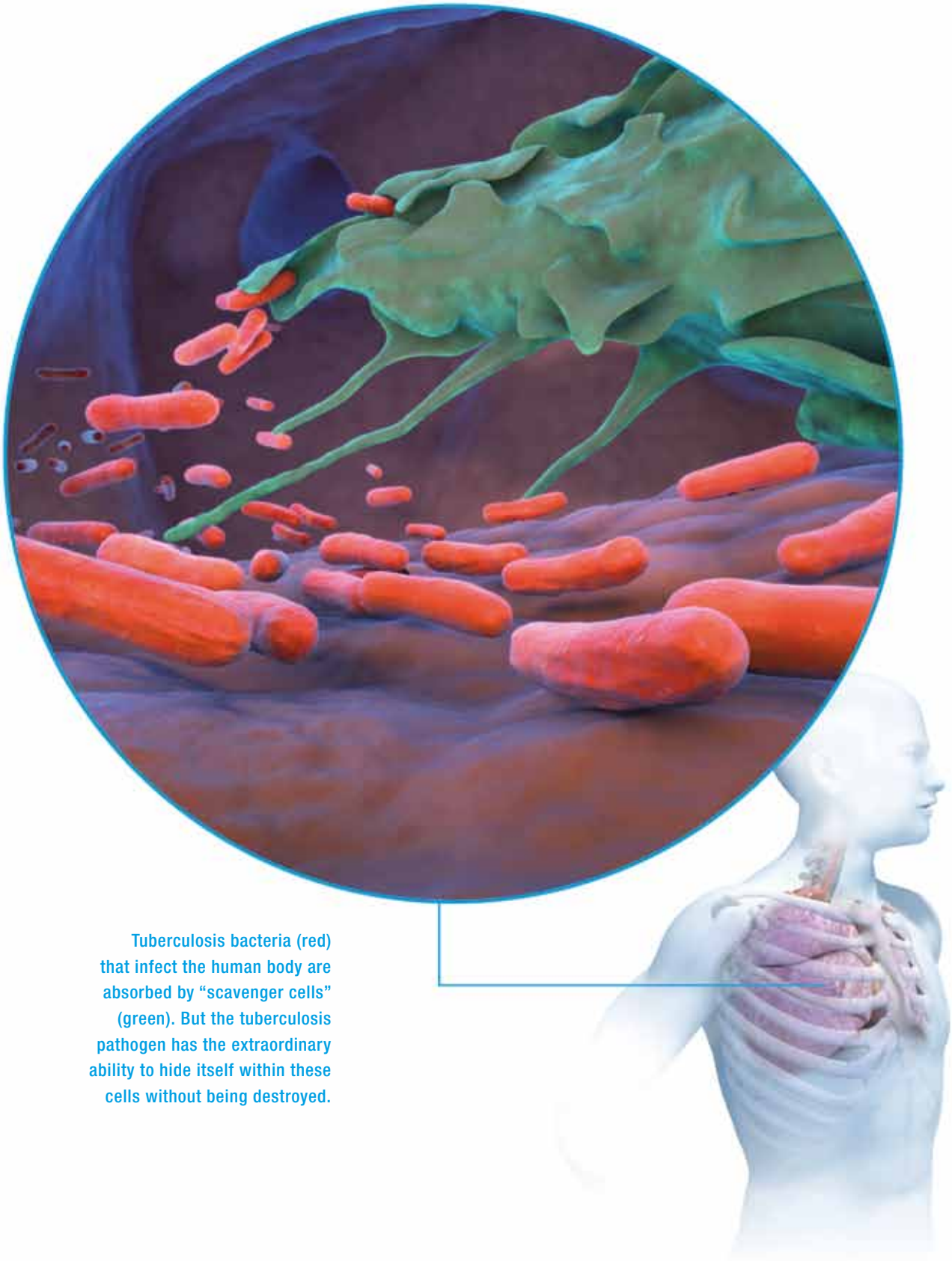
Prof. Dirk Heinz, Scientific Director of the Helmholtz Centre for Infection Research HZI

When biologists want to explore fundamental processes in cells or proteins, they often rely on physical methods. One of the most important techniques is X-ray structure analysis, whereby researchers expose proteins to intense X-ray radiation to decipher their structure and mode of operation. This makes it possible, for example, to identify the molecular mechanisms underlying the development of tuberculosis, one of the most dangerous infectious diseases.

The catch is that in order to be able to analyse proteins with X-rays, the proteins have to be crystallized. But many proteins cannot easily be forced into crystal form. In these cases, researchers can be glad if they succeed in growing tiny crystals of micrometre size. Such samples can only be studied with extremely fine X-ray beams of the kind supplied by the storage ring PETRA III.

Three experimental stations at PETRA III are operated by the European Molecular Biology Laboratory (EMBL), which maintains a research unit in Hamburg. One of the subjects the EMBL biologists have in their sights is the tuberculosis bacterium. "At DESY, we've so far been able to clarify the structures of about 50 proteins of this bacterium," says EMBL researcher Matthias Wilmanns. "Several of these could serve as possible points of action for future medicines that specifically target this pathogen and do not harm other, useful bacteria."

In the future, the experts intend to intensify their efforts at the Centre for Structural Systems Biology (CSSB), an interdisciplinary research institute on the DESY campus. CSSB is coordinated by the Helmholtz Centre for Infection Research; DESY and EMBL are major participating partners. "Among other things, we want to find out in detail how the tuberculosis pathogen slips its proteins into the human host cell," says Wilmanns. "Those are the weapons it uses to interfere with the metabolism of the human body."



Tuberculosis bacteria (red) that infect the human body are absorbed by “scavenger cells” (green). But the tuberculosis pathogen has the extraordinary ability to hide itself within these cells without being destroyed.

A boost for the nanosciences

With the NanoLab, DESY is stepping up its nanoscience research

Nanotechnology is considered a key technology of the future. Nanoscale components and structures will probably one day form the basis of extremely fast computers and intelligent new materials. At DESY, nanomaterials are already being systematically studied. By means of the X-ray flashes of PETRA III and FLASH, they can be probed in such detail that even the smallest features can be distinguished. To help analyse the nanoworld even more effectively, DESY is now creating a new laboratory, called the NanoLab.

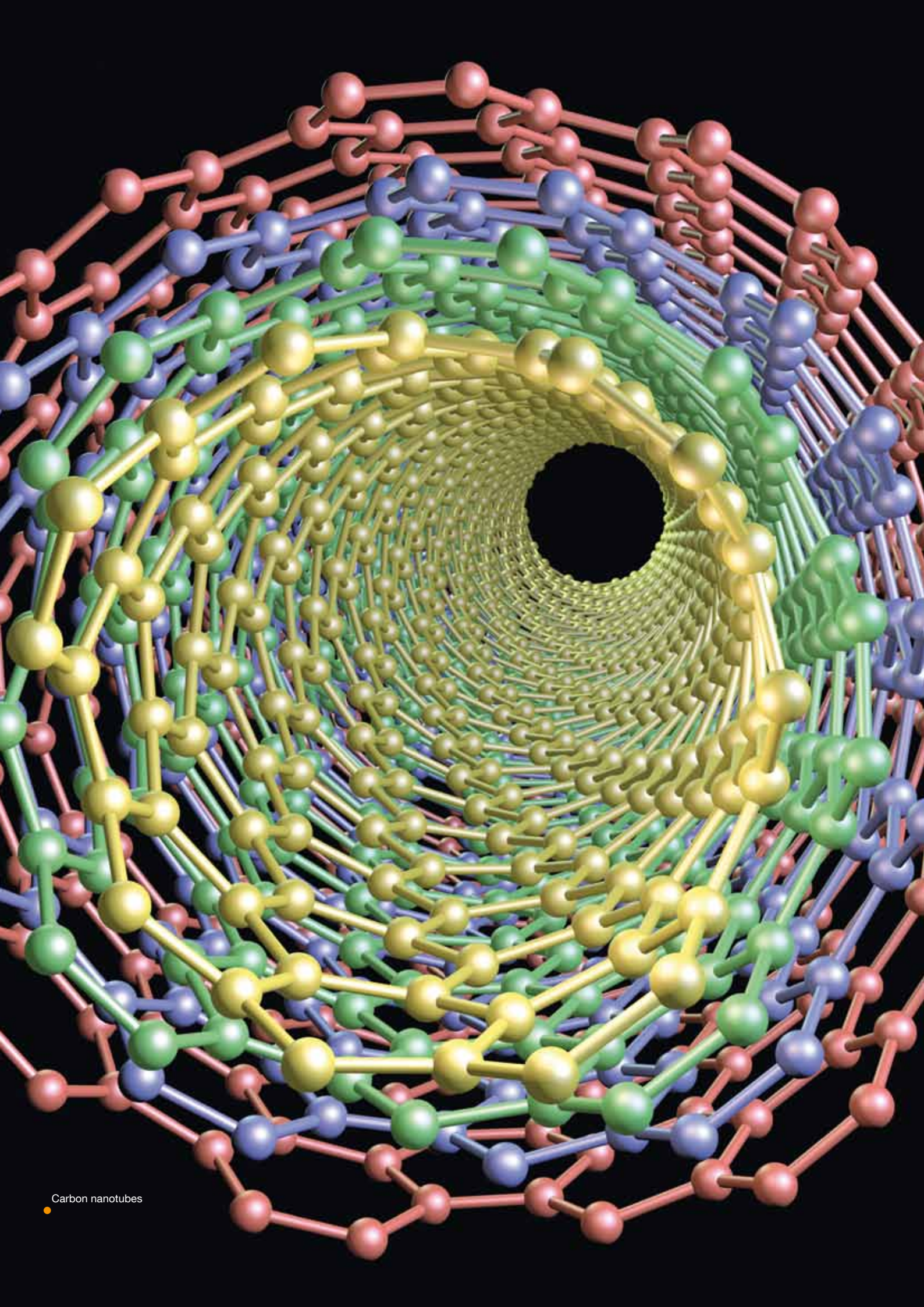
Generally, scientists wishing to examine material samples at DESY have to create and test these samples in their home laboratories before transporting them – often in special containers – to Hamburg in order to analyse them with X-rays from the accelerator. The NanoLab is expected to simplify this procedure. Beginning in 2014, it will provide about 1000 square metres of laboratory space where scientists can manufacture nanosamples and prepare them for the experiments.

One tool that will be used at the NanoLab is the “ion scalpel”, which can cut out tiny pieces from a material with a precision on the nanometre scale. Among other things, this is useful for the analysis of innovative metal alloys and multilayer stacks that exhibit unusual magnetic properties and may be suitable for use as data storage units.

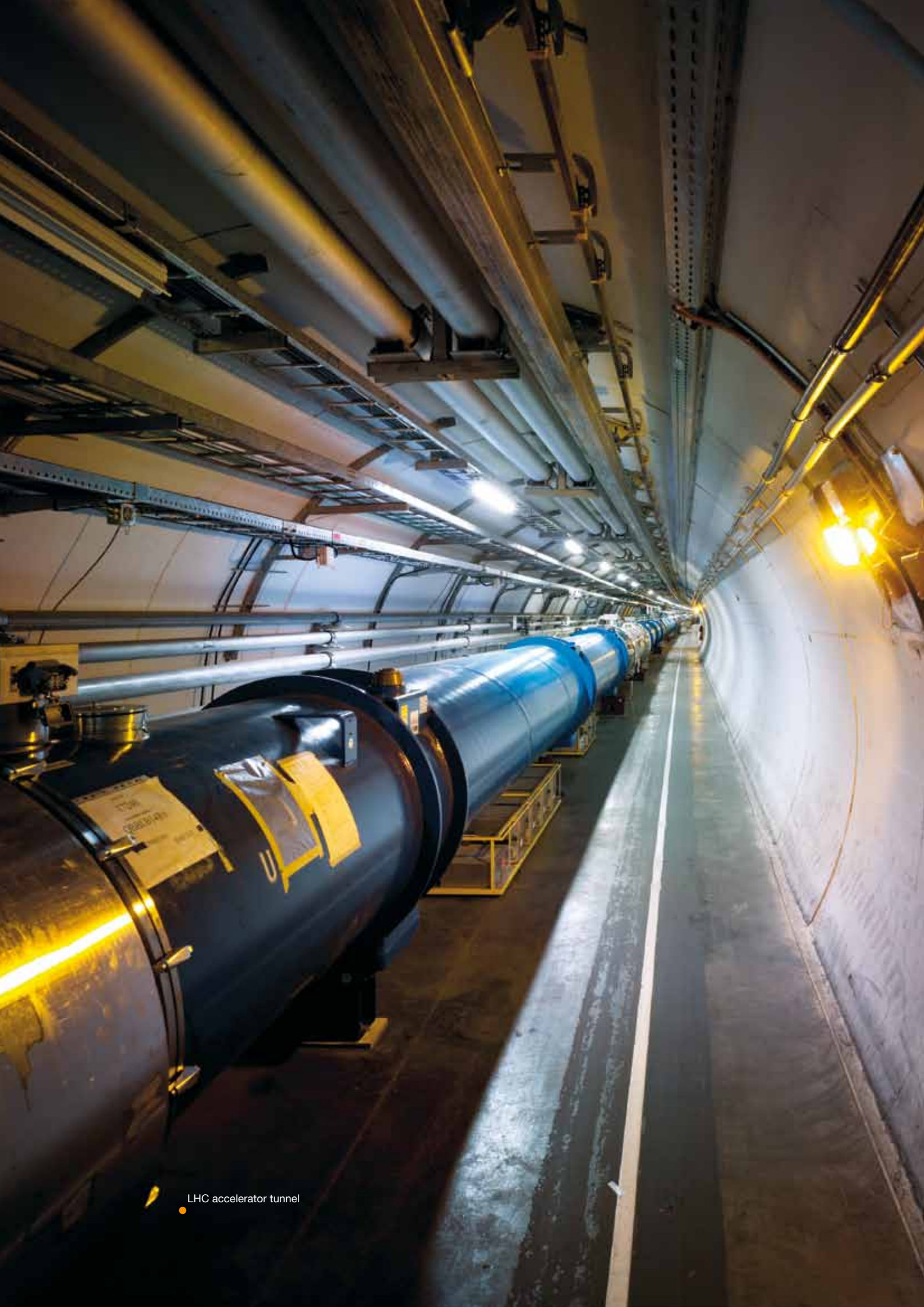
It isn’t just the many guest scientists who will benefit from the NanoLab. The new laboratory will also promote DESY’s in-house research. The Helmholtz-Zentrum Geesthacht has become the first partner to make a concrete contribution to the NanoLab.

A nanometre is one billionth of a metre. DESY’s super-microscopes probe the structures of this tiny world.

Structures from the nanoworld: nanofoam (left) and coating on aluminium (right)



Carbon nanotubes



LHC accelerator tunnel

The Geneva connection

DESY physicists are conducting experiments at the world's most powerful accelerator

"DESY is one of our most important partners, and its expertise has played a major role in the success of the LHC."

Prof. Rolf-Dieter Heuer, Director-General of CERN

It's the most powerful accelerator in history and currently the site of the most exciting particle physics experiment ever: the LHC, which accelerates protons to collisions at record energies. The 27-kilometre-long colossus thus has the potential to discover completely new building blocks of matter – as in the summer of 2012, when it detected a new particle believed to be the Higgs boson. The ultra-high-speed collisions in the LHC are monitored by detectors as tall as houses. Numerous DESY researchers are contributing their expertise to the experiments.

The two largest detectors in Geneva – ATLAS and CMS – are massive machines consisting of millions of highly sensitive individual sensors. Each experiment is managed by a large team of more than 2000 specialists from around the world, who jointly operate the detector and collect and analyse the data it produces. DESY itself has more than 100 experts working at ATLAS and CMS.

Among other things, the DESY experts help analyse the huge amount of data the detectors collect every day to search for signs of new particles – a task that is like looking for a needle in a haystack. The DESY specialists regularly travel to Geneva to operate the detectors in shifts or discuss highly complex data analyses with colleagues from around the globe.

The physicists have set up control rooms for both detectors at DESY, which allows them to remotely evaluate the quality of the data the experiments produce. In doing so, the DESY scientists benefit from their experience of operating the HERA accelerator in Hamburg.

Physics at the terascale

In 2007, the establishment of the Helmholtz Alliance "Physics at the Terascale" created a unique Germany-wide scientific network. This alliance brings together the activities of all the particle physicists who conduct research at the LHC super-accelerator in Geneva and work on plans for future accelerators. The alliance partners are DESY, the Karlsruhe Institute of Technology, the Max Planck Institute for Physics and 18 German universities. Among other things, the alliance supports the development of new technologies, assists with the analysis of complex LHC data and promotes up-and-coming scientists. DESY serves as the central hub of the alliance.

DESY – a research paradise

Brian Foster is Humboldt Professor in Hamburg

The Humboldt Professorship is Germany's most highly endowed international research award. Its recipients are granted five million euro in research funding for five years, which provides them with a great amount of scientific freedom. One of the lucky recipients is the British particle physicist Brian Foster, who in the summer of 2011 left the University of Oxford to join DESY, where he is now active in several research fields. "DESY is one of the world's best research facilities – the centre offers me outstanding opportunities for my work," Foster says. "I've worked here before, so being back at DESY is like coming home."

Foster's plans are ambitious and extremely varied. For one thing, he'd like to get back to some of his previous work and analyse data from the six-kilometre-long ring accelerator HERA at DESY – Germany's biggest accelerator of all time, which was used to collide electrons with protons up until 2007. "There's still a lot of interesting data from HERA that needs to be analysed. We'll be busy with it for years," Foster explains. One reason why the results are so important is that they improve the researchers' ability to evaluate data from the LHC super-accelerator in Geneva.

Foster also serves as the European director of the ILC project, a planned linear accelerator that would ideally complement the LHC. "The machine will be very sophisticated. We want it to be as good as possible, but we also want to keep construction costs low," says Foster. Even more ambitious are his plans for a completely new concept: a plasma accelerator. "This device promises to open up fantastic possibilities in the distant future. It's a machine that would fit into a hall rather than needing tunnels several kilometres long," Foster explains. "Here at DESY we're hoping to make spectacular progress with it."

What comes after the Humboldt Professorship ends? "I'm hoping to stay in Hamburg," Foster says. "It's hard to imagine finding working conditions as good as DESY's anywhere else."

"DESY is the one of the best research facilities."

Humboldt Professor Brian Foster

German-American particle friendship

OLYMPUS combines Hamburg accelerator with US detector

The physicist Richard Milner works and conducts research at MIT, one of the most prestigious elite universities in the USA. One day, he came up with an original idea: to combine a decommissioned particle detector from MIT with the DORIS accelerator at DESY in order to conduct exciting physics experiments – at a bargain price. Milner soon met with DESY experts, and their discussions led to the creation of a small but significant project known as OLYMPUS.

The OLYMPUS experiment focuses on a key aspect of the interaction of electrons and protons. When an electron flies toward a proton, the electromagnetic force acts on both of them and diverts the electron from its flight path to a greater or lesser degree. According to current particle theory, the electron-proton interaction in this scattering process involves an exchange of specific gauge bosons, the photons, which transfer the force between the electron and the proton. The question is: exactly how many photons are exchanged during such a scattering processes? Scientists expect that OLYMPUS can help answer this question by enabling them to study a fundamental building block of our world: the proton.

"The DORIS accelerator in Hamburg is perfect for this purpose," says Milner. "The detector fits precisely – almost miraculously – into the corresponding gap." The only thing that was needed to get the project going was a little conversion and redesigning work – and arrangements to transport the 50-tonne detector from Boston to Hamburg. As a result, OLYMPUS only costs slightly over one million euro, a modest sum for a particle experiment that now includes 50 experts from six countries. "The cooperation with DESY has been great," says Milner. "It will be an unforgettable experience for our students in particular, especially when we get our data at the end of 2012."

"The DORIS accelerator at DESY is perfect for our experiment."

Prof. Richard Milner, Massachusetts Institute of Technology MIT

The next generation

DESY is developing the accelerator and detector technologies of the future

While today's large-scale facilities are achieving groundbreaking results, experts at DESY are already planning the technologies of tomorrow. The next generation of accelerators and detectors will need to be significantly more powerful than previous ones if they are to help scientists chart hitherto unknown scientific territory. DESY is playing a key role in the international partnerships that are developing these pioneering technologies and transforming scientific visions into reality.

The TESLA accelerator technology, for example, which was developed at DESY in cooperation with international partners, is setting global standards. The superconducting resonators are being used on a large scale for the new European XFEL X-ray laser. TESLA technology also offers great opportunities for the coming generation of particle accelerators – that is, a future linear accelerator that would bring electrons and positrons to record energies, enabling scientists to examine new and exotic elementary particles, especially the Higgs boson, much more precisely than with means of the "discovery machine" LHC.

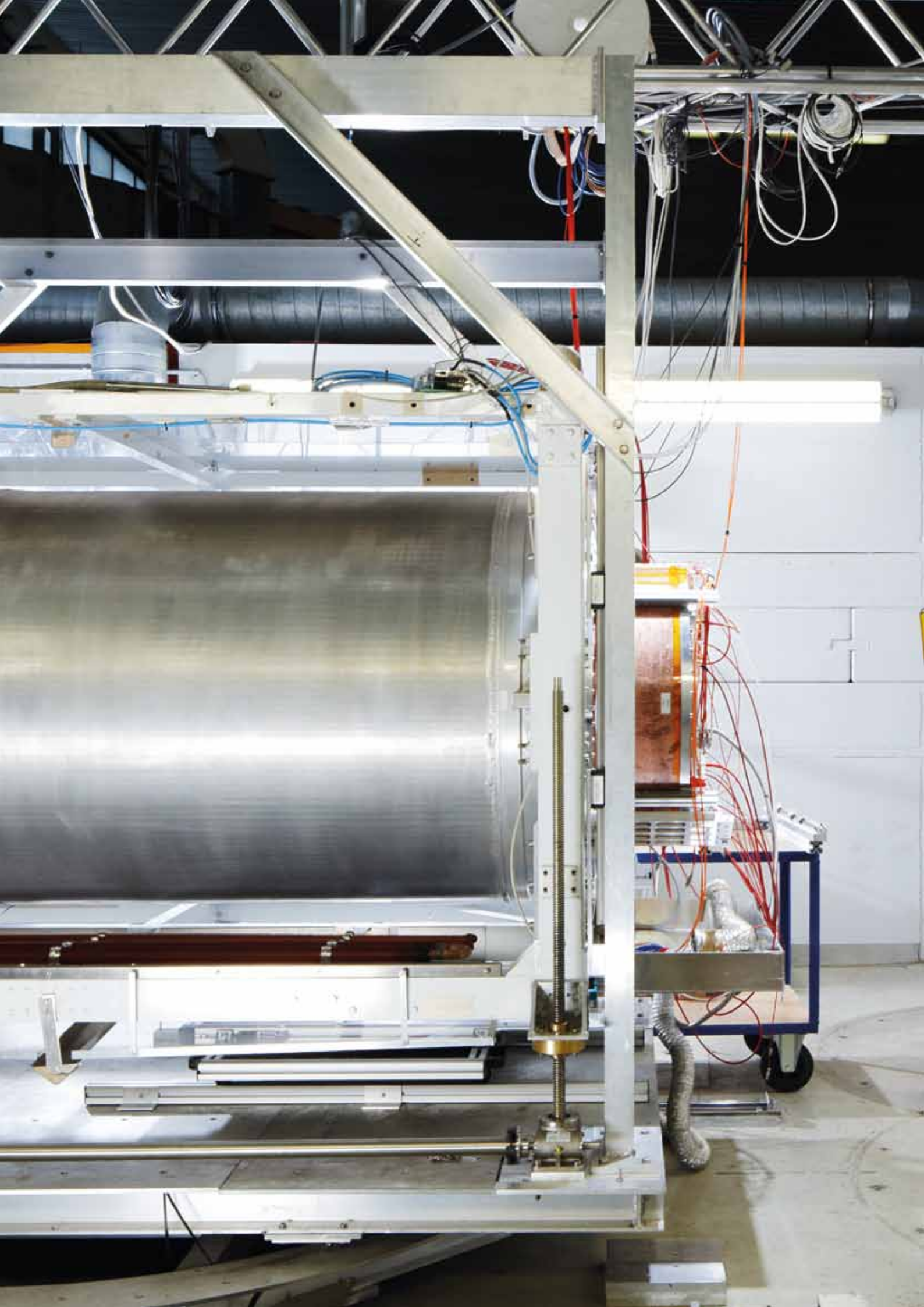
To this end, the superconducting TESLA resonators will have to meet even more demanding requirements than for the European XFEL. The nations engaged in particle physics research have joined together in a global effort to make the necessary refinements. Among other things, DESY is working to ensure that industrial companies can build resonators of reliable quality. Even tiny surface impurities could prevent the resonators from functioning properly. "That's why we had to develop highly specialized instruments," explains DESY physicist Eckhard Elsen. "These include clever cameras for quality control and sophisticated procedures for cleaning and polishing the insides of the resonators."

The detector systems of the future will also need to be much more sensitive and to react much faster than those used today. Large international research teams are now optimizing various detector technologies for measuring particle energy and tracks in order to meet the challenges associated with future particle accelerators. Plans also call for networking to be improved further. "The basic idea is not that everyone should do everything but instead that each of us should do what we do best," says DESY particle physicist Ties Behnke. That's why DESY is participating in numerous partnerships and projects with universities, Helmholtz institutes and other European and international partners.

"Global cooperation is becoming more and more important for the development of the accelerators of the future."

Dr. Eckhard Elsen, particle physicist at DESY

The KEK research centre in Japan has provided a special superconducting magnet for detector development activities at DESY.



Supporting desert power

DESY is helping to build bridges between Europe and North Africa

Giant solar power plants in the Sahara that supply Europe with climate-friendly electricity – that's the vision of the DESERTEC project. Specialists have been working on this plan for years, but several questions remain unanswered. One of them concerns the form that cooperation between European countries and North African nations should take. DESY is helping to shape the discussion process by contributing its extensive experience with major international scientific projects and partnerships.

The sun shines a lot more in the Sahara than in Europe, so solar power plants there operate more efficiently. Instead of solar cells, these facilities use large mirrors that concentrate sunlight by a factor of hundreds or thousands in order to vaporize water. The resulting steam is used to drive a turbine. The advantage of this approach is that it allows facility operators to store solar energy that was collected during the day as heat, thereby enabling the plant to supply electricity at night as well. However, building such solar power plants poses a huge challenge, which can only be overcome if the high-tech nations of Europe cooperate closely with the countries of North Africa.

To intensify this cooperation, DESY staged the "Solar Energy for Science – Building Bridges" conference in 2011. The event, which was held in Hamburg, brought together experts from various scientific disciplines and regions, enabling them to establish new contacts, discuss problems in detail and initiate new projects. The conference was so successful that follow-up events are now being planned. The Mediterranean region is set to become a centre of knowledge for addressing the major issues of our time: climate change, energy, health and water. The objective now is to establish sustainable research alliances between Europe and the nations of North Africa and the Middle East.

"The two stimulating days in Hamburg were a good starting point to better coordinate research agendas and to start building bridges towards a better future."

Environmental expert Prof. Klaus Töpfer on the DESY conference








"Solar Energy for Science" conference at DESY

"DESY's outstanding global network is strengthening the international position of the Helmholtz Association in a special way. DESY's research infrastructure, which is unmatched worldwide, serves as a platform for international cooperation and research at its best." *Prof. Jürgen Mlynek, President of the Helmholtz Association*

"DESY and KEK have been strengthening research cooperation since KEK's founding. Cooperation really makes us more productive and stronger. I am proud that KEK has been able to rely on the scientific partnership with DESY for so many years." *Prof. Atsuto Suzuki, Director-General of the KEK accelerator centre in Japan*

"Particle physics is bringing many countries together. Global teamwork not only leads to fascinating scientific results but also influences many areas of life such as education, technology and international understanding." *Prof. Rolf-Dieter Heuer, Director-General of CERN*

"We've been working closely and successfully with DESY for decades. DESY offers us ideal opportunities to study biomolecules in detail and thus learn more about the causes of disease." *Dr. Matthias Wilmanns, European Molecular Biology Laboratory EMBL, Hamburg*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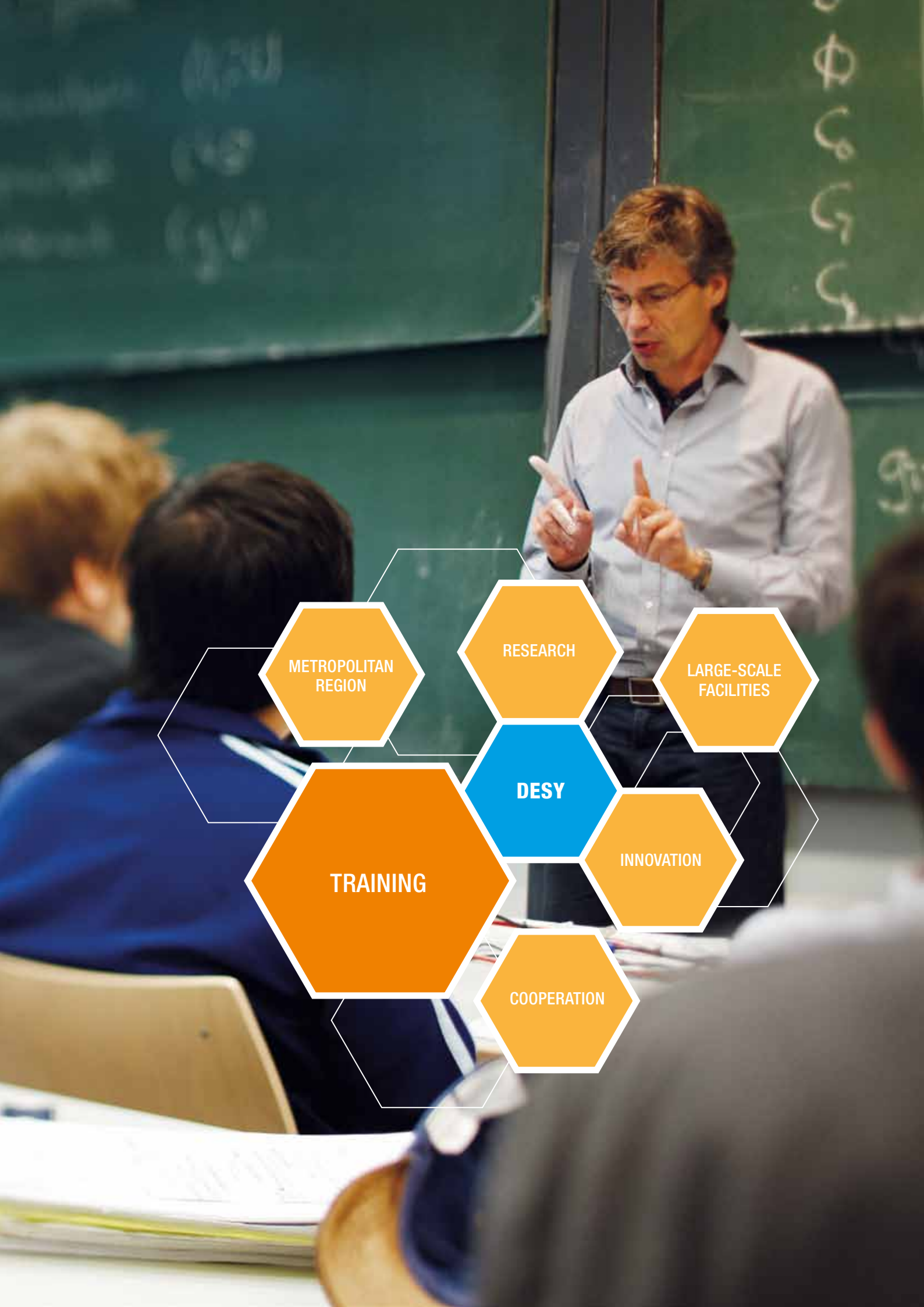
METROPOLITAN REGION
RESEARCH
LARGE-SCALE FACILITIES
DESY
TRAINING
INNOVATION
COOPERATION

TRAINING FOR TOP RESEARCHERS

DESY generates scientific insights and ideas for innovations. Just as important is its role as a nursery of young talents. DESY trains young people to be highly qualified, top-level scientists. Here, students and doctoral candidates learn how to develop their scientific creativity, juggle complex data and work in international and interdisciplinary teams. DESY graduates are coveted employees, not only in research institutes but also in business. This success is based on DESY's close networking with universities. At DESY, students complete their master's theses in a highly stimulating environment. Doctoral candidates from all over the world write their theses as part of top research projects – either directly in Hamburg or Zeuthen, or as guest scientists at one of DESY's X-ray sources. DESY has particularly close connections with the University of Hamburg. PIER, a strategic partnership between the two institutions that was founded in 2011, offers ambitious young talents top-level graduate training.

DESY also provides a variety of possibilities for starting careers in commercial-technical and business management professions. Young people can receive training in Hamburg and Zeuthen for future-oriented vocations such as industrial engineering, IT or technical product design. Schoolchildren can learn about science in the DESY school lab "physik.begreifen" – the oldest institution of its kind in the Helmholtz Association. Here, children nine or ten years of age on can make balloons or chocolate-coated marshmallows explode in a vacuum under a bell jar. Students from secondary schools can investigate whether certain salts are radioactive and how to shield the radiation. In the "Cosmic Lab", pupils in college preparatory classes can learn more about cosmic particles. The strong interest shows that this concept of teaching physics is effective: year after year, the school labs in Hamburg and Zeuthen are fully booked, with waiting lists.

PIER promotes young talents

DESY and the University of Hamburg offer outstanding prospects for talented young researchers

The close cooperation between DESY and the University of Hamburg has a long history. In 2011, this cooperation was intensified through the creation of a strategic partnership – the Partnership for Innovation, Education and Research PIER. PIER focuses on four ground-breaking areas of research: particle and astroparticle physics, nanosciences, photon science, and infection and structural biology. A central office coordinates the activities. It helps scientists to implement new ideas in research projects without bureaucratic obstacles. Tools such as the PIER ideas fund and workshops help to promote a dialogue with business and society.

"PIER is promoting an outstanding research-oriented training for our future scientists."

Dr. Christian Salzmann, Managing Director of PIER

Special emphasis is placed on the training of up-and-coming young scientists. In particular, the PIER Helmholtz Graduate School supports young researchers who are writing doctoral theses in these four research fields. A network of top researchers provides the doctoral students with support. With the help of the Helmholtz Association, PIER promotes regular stays at research institutions abroad and helps the doctoral students to build up networks with potential employers in industry and science. Outstanding candidates can apply for fellowships from the Joachim Herz Foundation.

Associated with the PIER graduate programme is DoIt, an initiative formed by the doctoral students at DESY. In 2006, they joined together to help newcomers orient themselves and create an active alumni network. DoIt regularly invites former DESY doctoral students to report on their current activities and thus give its members crucial support as they choose their future professions.

A promising career launch

Hundreds of young researchers are pursuing their first scientific research projects at DESY – where they find a highly international and interdisciplinary setting

DESY doctoral student Dörthe Kennedy is looking for previously undiscovered particles in the data of the LHC accelerator. For this purpose, she travels regularly to the European research centre CERN in Geneva. “There, I sit in the control room and help to monitor the experiments at the ATLAS detector,” she says. Because the facility operates around the clock, she sometimes has to do a night shift. “It’s exciting to work in the control room,” Kennedy says. “You realize that data are being collected this very minute – and exactly this data might ultimately reveal something new and exciting!”

The teamwork is also fascinating – after all, more than 2000 experts from all over the world are involved in ATLAS. “This works only thanks to a sophisticated group structure,” Kennedy explains. Researchers working on the same details have formed subgroups that share information on a weekly basis – through videoconferences, for example. Kennedy is cooperating with physicists in Bonn and Freiburg, as well as colleagues in the UK and Australia. What all of them have in common is a passion for discovery. “We’re very keen on analysing the data quickly and producing results!” says Kennedy.

Stefan Pabst, a doctoral student at CFEL, is working in the field of theoretical physics. He calculates how atoms behave when they are irradiated with intense ultrashort laser flashes. “Here at DESY, the research facilities I can use to test my theories are right next to my office door,” he says. Just as direct is his connection with the experimental physicists who are analysing their samples using the X-ray flashes from PETRA III or FLASH, or will be doing so using the European XFEL in the future.

There’s also another advantage that thrills Pabst. “At DESY, the work is very international,” he says. He works together with experts from South Korea, Canada and Russia, among others. “In the course of conversations you can find out what the scientific environment is like in other countries,” says Pabst. “In addition, you make contacts that can be very valuable later on – in my case, this might be after I complete my doctoral thesis, if I want to do research work abroad.”

DESY doctoral student Marc Wenskat is developing special software. The program automatically analyses the photographs taken by a camera that monitors the inside of resonators. This technology is useful for quality control, because even the smallest impurities or uneven spots can prevent the superconducting component from performing at its best. “What’s special about DESY is the incredible level of interdisciplinary cooperation,” Wenskat says. “Here, you’ve experts from a huge range of areas – biologists, medical researchers, physicists and IT specialists.”

The many seminars and advanced training courses that are regularly offered on the DESY campus ensure a lively exchange of ideas. “When you talk to experts from other fields, you sometimes get completely new and inspiring ideas for your own work,” says Wenskat, an accelerator physicist. “I’m a curious person, and at DESY I’ve got some great opportunities to satisfy my curiosity!”

Particle physicist Isabell Melzer-Pellmann has been leading a Helmholtz Young Investigators Group at DESY since 2010. At the LHC in Geneva, she is looking for particles that could explain the mysterious “dark matter”. “The Young Investigators Group is enabling me to build up my own research project with my own team,” she says. “I can decide independently what areas we’re going to work on.” The project will run for five years. During this time, Melzer-Pellmann will receive 1.5 million euro in research funding. Half of this amount will come from DESY, the other half from the Helmholtz Association.

The funding will enable Melzer-Pellmann not only to buy computers and cover travel costs but also to pay skilled employees. She has put together a strong team, consisting of four postdocs and four doctoral students, which will support her in her search for new particles using the CMS detector. The Helmholtz programme has become a launching pad for scientific careers. It’s not a rare for the leader of a Young Investigators Group to be appointed to a professorship before the five years of the project are up.

A doctoral student at the South Pole

Next-generation physicist Robert Franke spent two weeks doing research in the Antarctic

The trip there took five days – first by scheduled flight to New Zealand, then by military transport plane to McMurdo, a base station at the edge of Antarctica. From there, Robert Franke took a smaller plane to the middle of this inhospitable continent. As he climbed out of the airplane, he was standing at the southernmost point in the world – the US Amundsen-Scott South Pole station. "Everything was white and extremely bright. Without dark sunglasses, the light was just about unbearable," he says, recalling his first impressions.

The South Pole is the driest place on Earth – drier than any desert.

Franke is a doctoral student at the DESY location in Zeuthen. He is devoting his efforts to IceCube – a giant particle detector that searches for ghostly neutrinos from outer space within the eternal ice of the Antarctic. In January 2011, the young physicist travelled to the South Pole for two weeks to fine-tune the software for the mega-experiment on site. It's an extreme place to work, with temperatures down to around minus 30 degrees Celsius, air drier than in the hottest desert and dazzlingly bright sunlight. In January, the sun never goes down, as it's midsummer in the Antarctic. And no matter where you look, the landscape is white and completely level; it's as if you were living on a sheet of paper.

"I imagined that the cold would be much worse," says Franke. "You don't feel it as much because the air is so dry." On the other hand, the air is also rather thin, and that takes some getting used to. Because the research station sits atop a 3000-metre-thick ice shield, one gets out of breath faster than usual. Some new arrivals suffer from acute symptoms of altitude sickness and spend the first few days in the infirmary wearing an oxygen mask.

"The work days were long but exciting," Franke recalls. "The days started with the morning meeting, and then I would work on the detector, or I might assist at the station by helping to stow the food deliveries." He communicated with the rest of the world at night, when a satellite regularly flew over the South Pole. He slept in a rather barren little room – but it did offer a bit of privacy. His favourite leisure activity was to take a sauna followed by a radical cooling-off in the outdoor Antarctic air.

"What especially impressed me was the logistics at the station and the sense of community among the researchers," says the physicist. "At the Pole you meet all kinds of people from all over the world." If the opportunity arose, would he fly back there again? "Yes, definitely!" says Franke without hesitation – bitter cold, thin air and long travel times notwithstanding.

All wrapped up: in the Antarctic, Robert Franke had to protect himself thoroughly against the cold.

What became of them...

After their doctoral studies, DESY graduates have excellent opportunities in the job market

Edith Maurer works for the German Aerospace Center DLR in Oberpfaffenhofen. She supervises the operation of TerraSAR-X and TanDEM-X, two radar satellites for observing the Earth. Among other things, these satellites are taking a precise topographical picture of our planet. Maurer and her team make sure that the satellites record the data and that it is sent on to the scientists who will evaluate it. During her doctoral work at Technische Universität München, Maurer was a regular guest at DESY, where she examined polymers – plastic molecules – using X-rays.

"One of the things I learned at DESY was how to approach working on a scientific project. Carrying out an X-ray experiment is quite similar to working in a space flight control room right after a satellite is launched. In both cases, the project has to be constantly monitored – 24 hours a day, seven days a week. The preparation phase is also comparable. At DESY, I had to have the samples prepared right on schedule and the measurement times carefully planned to get all the experiments done. A satellite mission works in much the same way. The launch date is set. Everything has to be finished and ready by then. That can only be accomplished through good organization and perfect teamwork."

Linus Lindfeld is a patent lawyer at Airbus in Hamburg. During his doctoral work at DESY, he searched for hypothetical elementary particles called "leptoquarks" in the data of the H1 detector at the HERA accelerator. After his time at DESY, he spent three additional years training to be a patent lawyer at a law firm. This training included a law-oriented university distance learning course and an eight-month internship at the German Patent and Trade Mark Office and the Federal Patent Court in Munich. Now Lindfeld works for Airbus, where his job includes applying for patents for the company's new inventions.

"The analytical approach to problem-solving that is required in particle physics has helped me a lot. During my doctoral studies, I learned how to correctly interpret scientific results and how to deal with complex data. Especially valuable for my current job is the ability to filter a large amount of data and pull out what's truly important in the shortest possible time. DESY gave me an intensive education in that – kudos!"

During her doctoral work at DESY, Nanda Schmidt-Petersen developed a prototype for a new particle detector for future linear accelerators. Now she is doing additional training at a clinic in Stade to become a medical physics expert responsible for planning irradiation protocols for tumour therapy.

"Not only particle physicists but also doctors use accelerators – even though medical accelerators are a lot smaller. With these devices tumours can be effectively irradiated. We physicists make sure that the accelerators operate reliably. In addition, we fine-tune the equipment for each patient so that the tumour cells will be destroyed but neighbouring healthy tissue will remain as undamaged as possible. During my doctoral work at DESY, I learned the essential tools of the trade for my job: how does radiation interact with matter? The field of application is different, but the basic concepts are the same. And now I can use them in a concrete situation."

"PIER is intended as the central starting point for excellent science in the north of Germany. PIER will give the students at the University of Hamburg the opportunity to pursue their research work in a unique technological environment." *Prof. Dieter Lenzen, President of the University of Hamburg*

"The training of highly qualified top personnel for science and technology in Germany is one of our most important goals. Next-generation researchers bring new impetus and new ideas to the research process. Young colleagues learn from us and we learn from them." *Prof. Helmut Dosch, Chairman of the DESY Board of Directors*

"In the DESY school lab 'physik.begreifen' ('grasping physics'), we show school-children and young people how lively and exciting research can be. They carry out experiments themselves, and in that way they 'get a grasp' of physical relationships – in both meanings of the word." *Karen Ong, Head of the DESY School Lab*

"We offer diverse and challenging tasks in an international environment. We are looking for enthusiastic employees particularly in the areas of physics, electrical engineering, computer science and mechanical engineering." *Jochen Barnstedt, Head of DESY Recruitment*


Motivation
Leadership
Excellence
Flexibility
TRAINING


METROPOLITAN REGION
RESEARCH
LARGE-SCALE FACILITIES
DESY
TRAINING
INNOVATION
COOPERATION

IMPETUS FOR THE REGION

DESY is one of the most important and renowned institutions on the international research scene. But the centre's significance for the metropolitan regions of Hamburg and Berlin/Brandenburg is also growing. The DESY campus in Hamburg, in particular, strongly enhances the appeal of the region. Its large-scale facilities are major economic factors and attract researchers and doctoral students from all over northern Germany. Local residents are also fascinated by the research done at DESY. Groups of visitors, including schoolchildren, visit the centre regularly to find out about current research. Twice a month, visitors can come to the "Science Café DESY" to discuss scientific and technical topics with the experts. And on the DESY open days, the campus in Hamburg-Bahrenfeld attracts more than 10 000 visitors.

DESY is also creating jobs in both regions, as is documented by various studies. Approximately 2000 men and women are directly employed at the research centre. In addition, indirect economic effects safeguard more than 2000 additional jobs, most of them in northern Germany. In the 1980s, the construction of the HERA accelerator alone sustained and generated over 14 000 jobs in Germany. Similar figures apply to the European XFEL X-ray laser, which is currently being built and will go into operation in 2015.

The benefits for Hamburg and Berlin/Brandenburg are not merely material ones. For example, DESY cooperates closely with the universities and institutes in the region and offers them unique opportunities for research and training, especially for up-and-coming young scientists. And the fact that DESY attracts thousands of experts from all over the world every year lends the regions renown and international flair.

A high in the north

The DESY campus in Hamburg is setting benchmarks

University of Hamburg – a strategic partner

Since 2011, DESY and the University of Hamburg have been working together even more closely than before. They have launched a cooperation called PIER, or Partnership for Innovation, Education and Research, which is more strongly networking the two institutions' research and training activities and also promoting their transfer of science and technology throughout the Hamburg region. For example, the PIER workshops bring together excellent researchers who share and discuss unusual ideas – a creative setting for outstanding thinkers from the region. The PIER ideas fund helps young scientists by speedily providing them with initial funding so that they can quickly and unbureaucratically implement brilliant ideas. Because most of these young experts go into the business sector after completing their education, the ideas fund is strengthening the regional high-tech industry.

Fruitful nano cooperation

Since 2005, the Center for Applied Nanotechnology (CAN) in Hamburg has conducted commercially relevant research projects in the field of nano-science. CAN carries out research commissioned by high-tech companies and manufactures nano-particles, for example for medical diagnostics or new types of solar cells. DESY became a member of the CAN sponsoring association in 2012. Both institutions can now cooperate more closely than before and undertake joint projects in medicine, energy research or materials science. The analytic methods of CAN and DESY ideally complement one another, giving an additional boost to nano-technology in Hamburg.

A technology park near DESY

Hamburg intends to become a leading location for high tech in the coming decades. To intensify the interaction between science and commerce and promote the establishment of new high-tech enterprises, the city is planning to set up six technology parks. Plans call for one of these Hamburg Innovation Parks to be built directly adjacent to DESY. Companies that settle there would have easy access to X-ray sources like PETRA III and the European XFEL for tasks such as the analysis of innovative nanomaterials and biomaterials. DESY would benefit as well: a well-working technological setting in the immediate vicinity can be very helpful for a research centre's ability to develop.

Successful Excellence Initiative

Through the Excellence Initiative, the German government and the federal states are strengthening top-calibre research at the country's universities. A central component of the initiative is the Excellence Clusters. These bring outstanding scientists together so that they can work as a team in an innovative research area. Together with the University of Hamburg, CFEL and European XFEL, DESY is a member of the Excellence Cluster "Hamburg Centre for Ultrafast Imaging". Its researchers are developing new methods for light sources such as FLASH in order to "film" chemical reactions as they occur.

Excellence in the region

In 2009, the Free and Hanseatic City of Hamburg established its own Excellence Initiative. Its aim is to strengthen and promote cooperative research projects between Hamburg universities and other institutes and universities. As a central partner of this initiative, DESY is participating in three of Hamburg's six Excellence Clusters:

Connecting Particles with the Cosmos
Physicists are investigating the fundamental laws of the universe and combining data from particle accelerators and telescopes with the most recent theoretical knowledge.

Frontiers in Quantum Photon Science
Scientists are experimenting with new types of laser facilities and X-ray sources to understand the details of the interactions between light and matter.

Nano-Spintronics
Experts are examining the possibilities opened up by a new and promising type of electronics. "Spintronics" could one day enable super-fast computers and data storage units with gigantic capacities.



Cooperation with Kiel

DESY has been cooperating with the University of Kiel since the 1970s. In 2011, this cooperation was intensified and the Ruprecht Haensel laboratory was established. As a result, research groups from Kiel can play a much more active role in the development and use of the X-ray sources at DESY. The scientific topics range from biology and chemistry to electrical engineering, materials science and fundamental issues in physics. The cooperation includes the establishment of two working groups with jointly appointed professorships.

Jobs for northern Germany

A new centre for top-level research is generating momentum for growth within an entire region. Even in its start-up phase, the European XFEL is creating additional jobs, turnover and income in northern Germany. According to a study conducted by business researchers at the University of Hamburg, the project is creating 1350 jobs every year during its construction phase, most of them in the Hamburg region. DESY and its suppliers are the source of about half of the jobs and the income that is being generated. The sectors that are benefiting the most are trade, construction, financial services and mechanical engineering. The other half of the jobs and income is due to indirect effects: employees are spending their pay in the region and thus strengthening the retail trade, the real estate sector and the services industry. This means that the investments in the European XFEL, more than half of which come from Germany, are bringing about significant growth and innovation effects.

But it's not only the construction of new research facilities that is enhancing growth in the region. DESY itself is an important employer, providing jobs for about 2000 employees and more than 100 apprentices in commercial-technical and business management professions. In addition, DESY attracts over 3000 guest scientists from more than 40 countries every year and provides research opportunities for about 700 diploma candidates, doctoral students and postdocs. If all these scientists are to do their work successfully, they need an appropriate infrastructure. This includes specialized workshops and large computer centres as well as an administrative structure, a comprehensive library, a canteen and a cafeteria.



Crowds of visitors on the DESY campus

Almost 14 000 visitors on a single day – that's the impressive contribution DESY made to Hamburg's Science Night in October 2011. On this occasion, visitors gained a lively impression of scientific research at 60 different locations throughout the centre, including the FLASH X-ray laser, the gigantic experimental hall of PETRA III and the workshops and school laboratories at DESY. The event shows that the research centre has become an integral part of life in Hamburg. DESY opens its doors to the public every two years, and each of these open days attracts more than 10 000 visitors. In addition, school classes, groups of students and other interested visitors come every day to tour the research centre. Physics students act as tour guides and offer the visitors a lively impression of the many different kinds of research conducted at DESY.

DESY is also a regular participant at events such as the Hamburg Harbour anniversary celebration. Over and over again, the centre demonstrates that its researchers don't work in an ivory tower.


Donau
Goethestraße
Platanenallee

DESY in Brandenburg

The campus in Zeuthen generates momentum for the entire region

Closely connected with Berlin/Brandenburg

After the German reunification, the GDR's Institute of High-Energy Physics became the DESY location in Zeuthen, which is today one of the largest scientific institutions in the federal state of Brandenburg. DESY in Zeuthen operates its own top-class accelerator, the PITZ photo injector test facility, and serves as a national centre for astro-particle physics. The centre is ideally networked with the Berlin/Brandenburg region. DESY in Zeuthen has joint appointments with the University of Potsdam and Humboldt University in Berlin, and it also cooperates with other universities and research institutes. DESY participates in a variety of regional networks, including the Berlin-Brandenburg cluster and the Potsdam Research Network "pearls"; it is an important partner for science and business.

Investing in the future

DESY in Zeuthen is strongly involved in the promotion of up-and-coming young scientists. Its offerings for students, its traineeships and internships and its school laboratories on the topics of vacuum and the cosmos are highly coveted and quickly booked out. In addition, DESY maintains partnerships with schools and regularly participates in events such as the Future Day for boys and girls and the Science Night in Berlin and Potsdam. Through these programmes, DESY in Zeuthen is engaging in general education for children and youth and encouraging especially talented young people in particular.

The window to the cosmos in Zeuthen

The Earth is continually being bombarded by particles from space, which provide information about the distant parts of the cosmos. Researchers in Zeuthen are using two types of these heavenly messengers – neutrinos and high-energy gamma rays – to investigate the secrets of star explosions and cosmic particle accelerators. These open questions of astroparticle physics are an exciting challenge to scientists – and to young people. DESY enables high-school students to experience at close range various issues associated with cosmic radiation. Scientists offer support to interested students and enable them to experience their research "live". As part of the network "Teilchenwelt", DESY in Zeuthen has developed an especially interesting project. At universities and institutes all over Germany, young people can carry out simple experiments to find out how cosmic particles are detected and what they tell us about the universe. These cosmic experiments give the participants a realistic insight into the daily work of astroparticle physicists.

"DESY is a renowned research centre where scientists from all over the world achieve brilliant results. DESY is developing into a unique interdisciplinary campus where top-level research is being done in close cooperation with the University of Hamburg, among others. And that top-level research is taking place in a process of lively communication with the city, its citizens and the companies that are located here." *Olaf Scholz, Mayor of the Free and Hanseatic City of Hamburg*

"DESY in Zeuthen has developed into an important source of momentum for the region." *Prof. Christian Stegmann, Director of the DESY location in Zeuthen*

"In Zeuthen, something has been created that will reach far into the future. By strengthening astroparticle physics and launching new projects in accelerator physics, DESY in Zeuthen has sharpened its profile in a very impressive way." *Prof. Sabine Kunst, Minister of Science of Brandenburg*

"DESY is an important cooperation partner in the Hamburg region, especially for the development of high technology." *Christian Scherf, DESY Director of Administration*


Synergy
Communication
Fascination
METROPOLITAN REGION

IMPRINT

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Impetus for the region

Training for top researchers

A strong cooperation partner

Innovations for society

Research for the future

Large-scale facilities for science

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Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

The Helmholtz Association is a community of 18 scientific-technical and biological-medical research centres. These centres have been commissioned with pursuing long-term research goals on behalf of the state and society. The Association strives to gain insights and knowledge so that it can help to preserve and improve the foundations of human life. It does this by identifying and working on the grand challenges faced by society, science and industry. Helmholtz Centres perform top-class research in strategic programmes in six core fields: Energy, Earth and Environment, Health, Key Technologies, Structure of Matter, Aeronautics, Space and Transport.

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