# femto

The DESY research magazine – Issue 01|14

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Dear Reader,

This is the first issue of *femto*, the new DESY research magazine. In future, it will report four times a year on the latest scientific discoveries at the DESY research centre.

*femto* invites you to join us on a journey of discovery into the fascinating world of research at DESY. The journey will take us back to the origins of our universe and into the hidden dimensions of the quantum world. We'll come back from our travels bearing brilliant snapshots and live images of the movement of atoms and molecules in new materials and in living nature. *femto* will also give you up-to-the-minute insights into the latest DESY technologies. These include our superconducting accelerators, which bring electrons to the highest energies with optimum efficiency, as well as our ultramodern detectors and innovative lasers.

Through *femto*, you'll also stay up to date with the research and development work done by our partners on the DESY research campuses in Hamburg and Zeuthen as well as our approximately 3000 guest scientists, who play a major role in making DESY a multidisciplinary, multicultural and multinational centre of research.

Our first *femto* journey will lead you into the uninviting world of pathogens. Focusing on the theme of infectious diseases, this issue of *femto* will show how biologists, medical researchers and physicists are working together to find new ways to combat bacteria and viruses. What role are the large-scale facilities at DESY playing in the effort to meet this global challenge? You will find the answer in this issue.

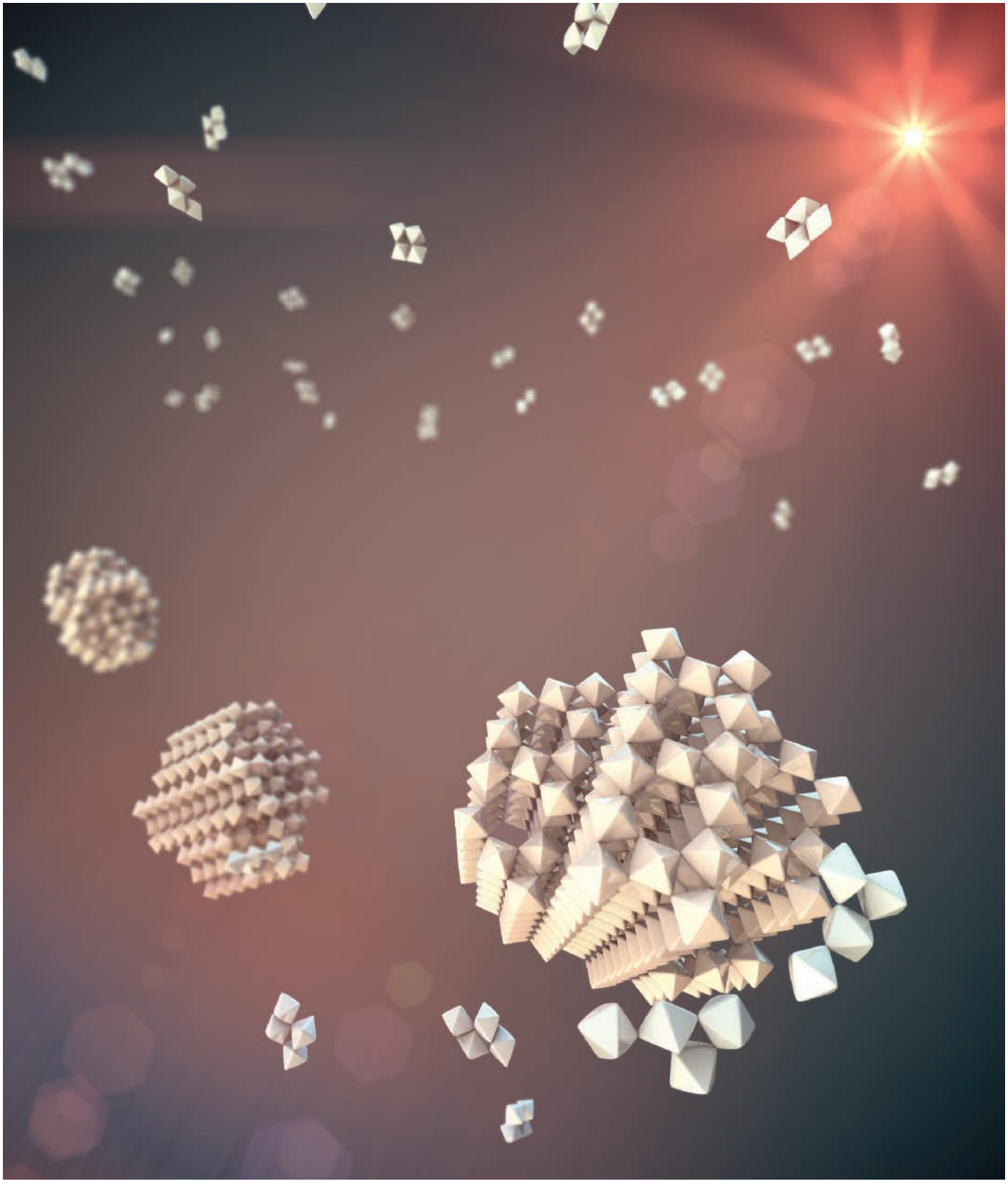
Femto is the prefix normally used to signify a quadrillionth ($10^{-15}$) of a measuring unit such as a metre or a second. For DESY, it's a symbol of the advance into the world of the tiniest particles and into the unknown. It has lent its name to our new research magazine as a prefix for future scientific discoveries and innovations from the DESY research centre.

If you like *femto*, you can order a free subscription! You can find out how to do so at the back of this issue.

We wish you a pleasant and exciting reading experience as you browse through this first issue of our research magazine.

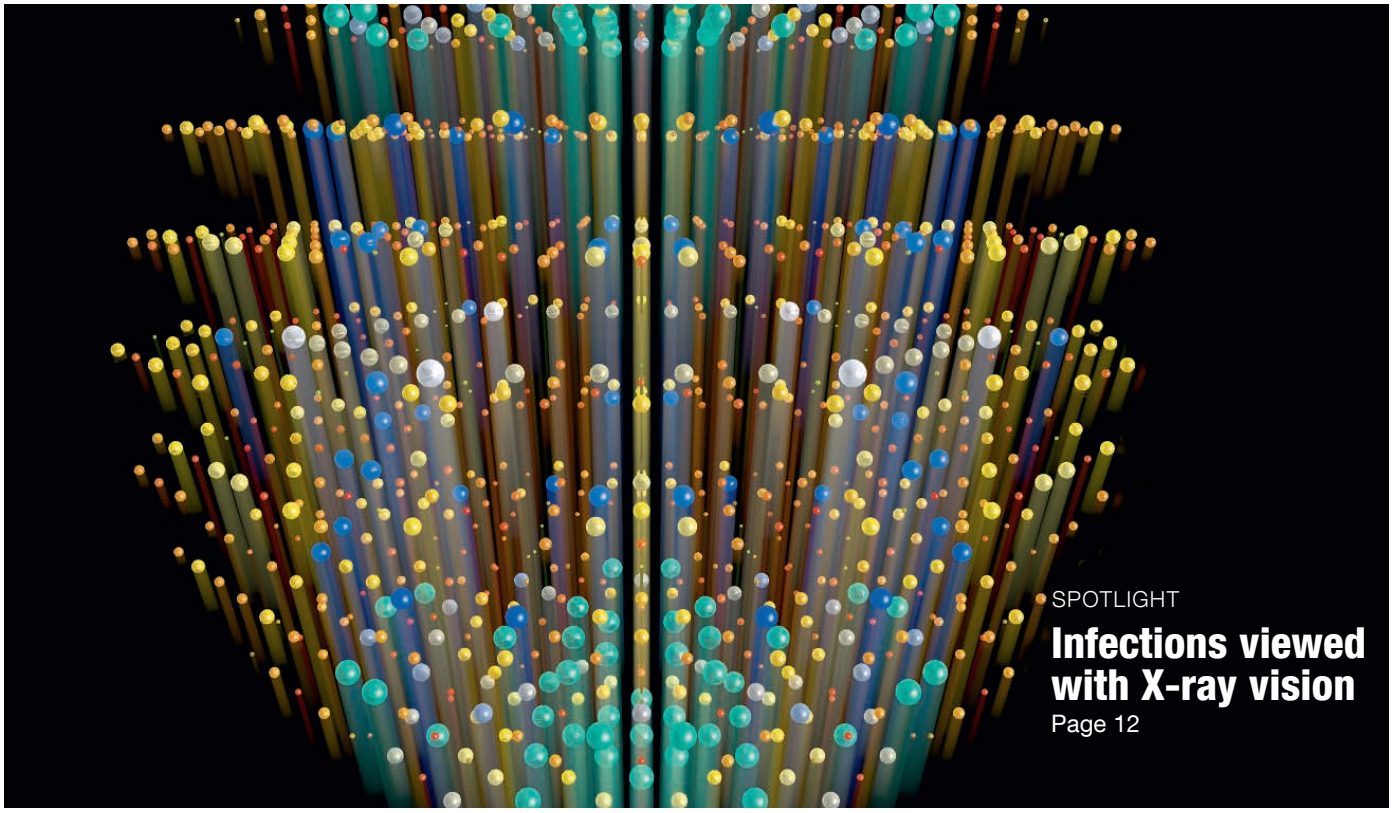
Sincerely yours,

Helmut Dosch
Chairman of the DESY Board of Directors



# Powers of ten

For the first time ever, Danish researchers have been able to watch the growth of ten-nanometre-high towers of tungsten trioxide in a solution at DESY's PETRA III X-ray radiation source. One of the uses of such nanoparticles is in smart windows that become opaque at the push of a button. The nanoparticles are also used in certain kinds of solar cells. The X-ray measurements show not only the nanostructures at the atomic level but also the dynamics of the growth process. Depending on the manufacturing conditions, the tungsten trioxide particles bond to form either ordered or disordered structures. Such research findings can now be used to equip nanomaterials with specific properties and customise them for new technologies. Picture: Lucid / DESY



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Infectious diseases are among the greatest challenges of our time. Our weapons against dangerous pathogens are at risk of becoming blunted, as show strains of bacteria that are already resistant to all current antibiotics. Structural biology offers promising new approaches to this challenge. With the help of intense X-ray radiation, researchers can decipher the way biomolecules function and find starting points for customised medications.

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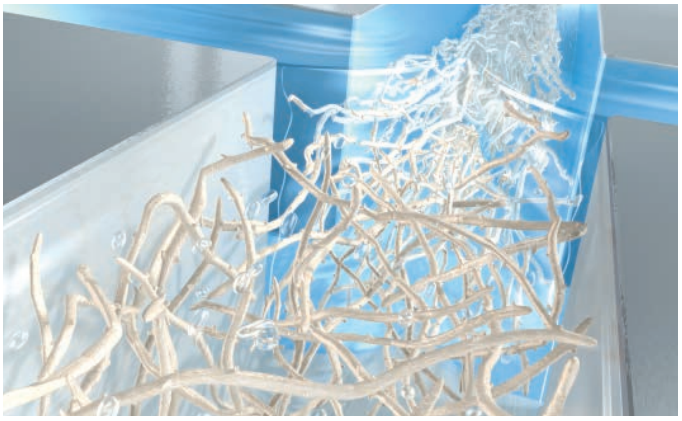

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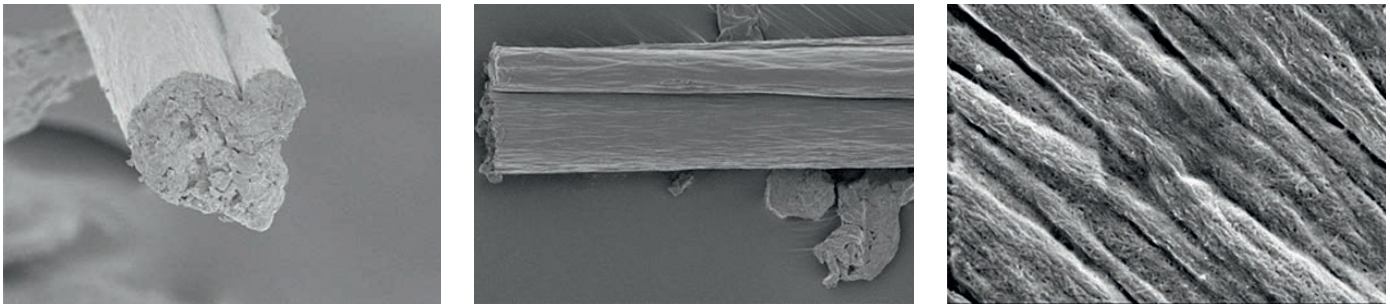
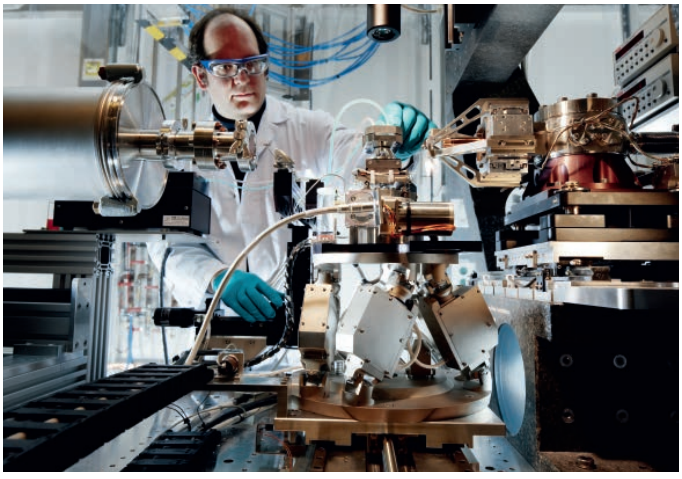


**Ultrastrong:** Artificially produced cellulose fibres under the scanning electron microscope. Picture: Fredrik Lundell / KTH Stockholm

# Stronger than steel

## Scientists spin ultrastrong cellulose fibres

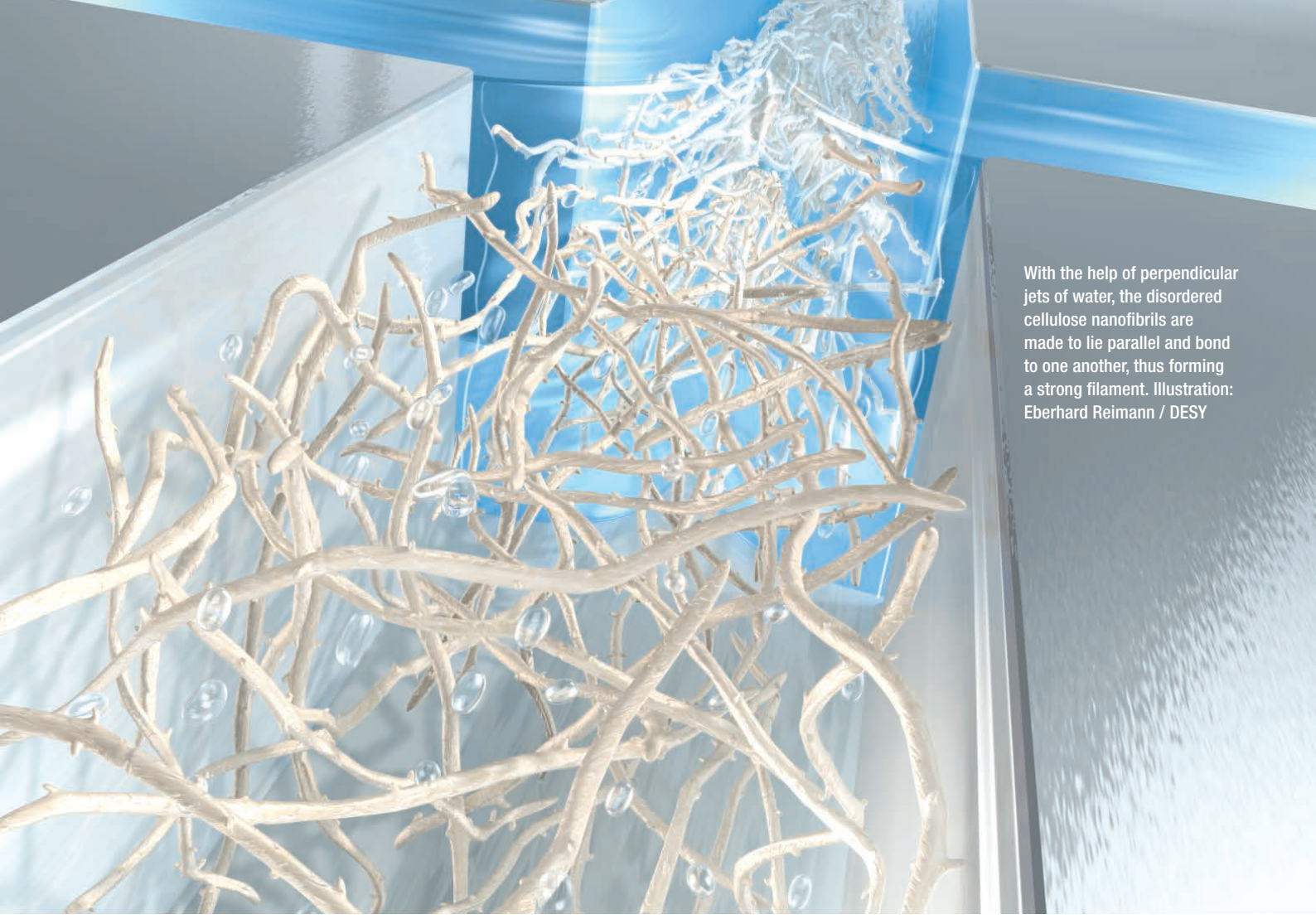
**In the future, will we live in houses that have been printed in a gigantic 3D printer using innovative cellulose fibres? Fibres that come from recycled paper but are ultrastrong and completely sustainable? This is a bold vision of the future, but a new process for producing extremely strong cellulose fibres offers a very promising approach to just that.**



DESY researcher Stephan Roth at the P03 experimental station. Picture: Heiner Müller-Elsner / DESY

A Swedish–German research team at DESY has successfully tested an innovative method for spinning ultrastrong filaments from nanometre-sized cellulose fibres. Cellulose is the main component of the cell walls of plants, where it forms tiny fibres called fibrils. Thanks to the novel procedure, these fibres are all aligned in parallel and thus become extremely tough. “Our filaments are stronger per weight than both aluminium and steel,” emphasises the lead author of the study, Fredrik Lundell from the Wallenberg Wood Science Center at the Royal Institute of Technology KTH in Stockholm, Sweden. “The real challenge, however, is to make bio-based materials with extreme stiffness that can be used in wind turbine blades, for example. With further improvements, in particular increased fibril alignment, this will be possible.”

For their method, the researchers feed the tiny, nanometre-sized cellulose fibrils together with water through a small channel. Two additional water jets coming in from both sides accelerate the



With the help of perpendicular jets of water, the disordered cellulose nanofibrils are made to lie parallel and bond to one another, thus forming a strong filament. Illustration: Eberhard Reimann / DESY

fibril flow. "Due to the acceleration by these jets, all of the nanofibrils align themselves more or less parallel with the flow," explains Stephan Roth, head of the P03 experimental station at DESY's X-ray radiation source PETRA III, where the experiments took place. "In addition, the jets add salts to the flow. These salts make the fibrils attach to each other, thereby determining the structure of the future filament." Finally, the wet filaments are left to dry in air, where they shrink to form a strong fibre. "Drying takes only a few minutes in air," explains Daniel Söderberg from KTH. "The resulting material is completely compatible with the biosphere, since the natural structure of the cellulose is maintained in the fibrils. It is thus biodegradable and even compatible with human tissue." The bright X-ray light from PETRA III allowed the researchers to follow the production process in detail and check the configuration of the nanofibrils at various stages in the flow. "Research today is driven by cross-disciplinary collaboration," Söderberg emphasises. "Without the excellent competence and possibilities brought into the project by the team at DESY's P03 experimental station, this would not have been possible."

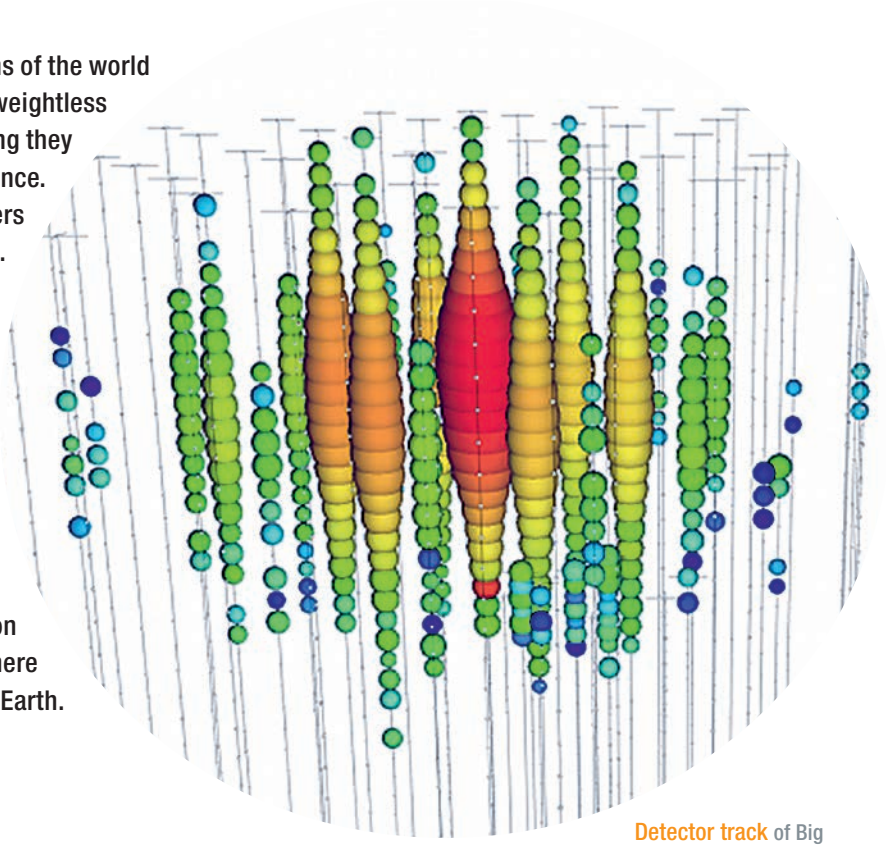
According to the scientists, their filaments are much stronger than all other previously reported artificial filaments made of cellulose nanofibrils. In fact, they can even rival the strongest natural cellulose pulp fibres extracted from wood, and they have the same high degree of parallel alignment of the nanofibrils. "In principle, we can make very long fibres," says Lundell. "Up until now we have made samples that were ten centimetres long or so, but that is more of a technical issue than a fundamental problem." For their experiments, the researchers used nanofibrils extracted from fresh wood. "In principle, it should be possible to obtain fibrils from recycled paper also," says Lundell." But the potential of recycled material in this context needs further investigation."

Reference: Hydrodynamic alignment and assembly of nano-fibrils resulting in strong cellulose filaments; Nature Communications, 2014; DOI: 10.1038/ncomms5018

# Big Bird

**At the South Pole, the world's largest particle detector has registered the most energetic cosmic neutrino ever measured**

**Neutrinos are the phantoms of the world of elementary particles. They are almost weightless and penetrate everything they encounter with virtually no interference. That makes them unparalleled messengers of spectacular events in outer space. They can help us find answers to questions such as: 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 as cosmic radiation? Neutrinos are not affected by matter or magnetic fields. This enables them to provide us with information about regions of space from where almost no other signal reaches the Earth.**



**Detector track** of Big Bird, the most energetic neutrino ever measured. The spherical detection devices are sunk like pearls on a string in the Antarctic ice, where they measure the light signals generated by neutrinos. Picture: IceCube Collaboration

Due to their lack of interaction with other particles, however, neutrinos are also rarely caught in terrestrial measuring devices. To detect the ghost particles from the depths of space at all, researchers had to build the world's largest particle detector, which is located at the South Pole. Called IceCube, it encompasses a full cubic kilometre of Antarctic ice, into which the researchers sank 86 steel cables. On these cables hang a total of 5160 sensitive detection devices known as optical modules, which watch for the weak flashes of light that the rare neutrino collisions generate.

The search for the cosmic messenger particles was crowned with success in 2013, when the approximately 260 international experts involved in the IceCube project discovered two extraterrestrial neutrinos, which they humorously dubbed Ernie and Bert in honour of two characters from *Sesame Street*. The two neutrinos had unusually high energies of more than 1000 teraelectronvolts. That makes them stand out from the innumerable other neutrinos that are continually created in the Earth's atmosphere and are much less energetic. This first indication

**Cosmic superaccelerator:** Black holes and active galactic nuclei are suspected to be among the sources of very energetic cosmic particles. Picture: NASA / Goddard Space Flight Center / CI Lab

of high-energy neutrinos from outside our solar system was celebrated with great enthusiasm. The finding was supported by another thorough analysis of the IceCube data, which revealed 26 additional events involving energies of over 30 teraelectronvolts. Big Bird was found next: in April 2014, at a scientific conference in the USA, IceCube researchers announced that they had found the most energetic neutrino ever discovered. They named it Big Bird after another character from *Sesame Street*. Big Bird has around twice as much energy as its fellow neutrinos Ernie and Bert. By way of comparison, the neutrino from the depths of space has 500 times more energy than the protons brought to collision in the world's most powerful particle accelerator, the LHC near Geneva. Here, physicists cause protons to collide with one another at almost the speed of light in order to discover spectacular new particles such as the Higgs boson. However, the South Pole researchers are not driven by the desire to achieve new records. Instead, IceCube is about to open a new window onto the cosmos. "We are currently witnessing the birth of neutrino astronomy," says Markus Ackermann, head of DESY's neutrino astronomy group. So far, the researchers have not yet discovered enough of these events to determine if there is a chronological or spatial clustering that would give us an indication of the particles' cosmic source. "We are now working hard to increase the significance of our observations and to understand what this signal means and where it comes from," explains the spokeswoman of the international IceCube project, Olga Botner from the University of Uppsala in Sweden. The scientists hope that a growth in the number of detected events will enable them to identify individual cosmic sources of the energetic neutrinos.

## Who stole Ernie's ice cubes?

### What IceCube has to do with *Sesame Street*

**Even the scientists in major global projects sometimes need to get away from the hard facts and figures that are their daily bread and butter. That's why a doctoral student involved in the IceCube project dubbed the first high-energy neutrinos "Ernie" and "Bert" to give the abstract events an almost tangible existence. One of the episodes of the beloved children's show *Sesame Street* actually deals with ice cubes.**

**However, Ernie's ice cubes are much smaller than the one-cubic-kilometre-large detector at the South Pole, and they fit into a box in which Ernie wants to present an ice cube collection to his friend Bert. Unfortunately, the box only contains a puddle of water by the time it is shown to Bert. This causes Ernie to speculate wildly that fish may have stolen the ice cubes, while Bert vainly tries to make his friend understand that ice melts when it is taken out of the freezer.**

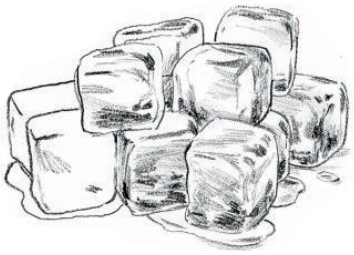


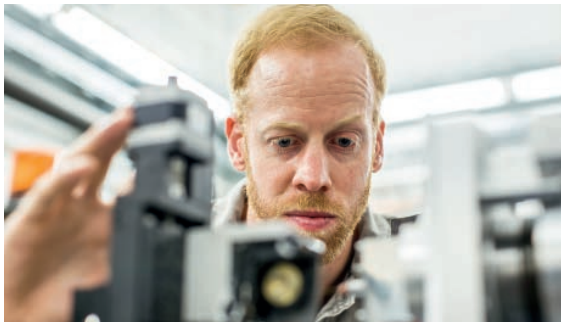
Illustration: Anja Stiehler – Jutta Fricke Illustrators / DESY

# PETRA tests lipsticks

## Kiss-proof in all types of weather

*Although lipstick is generally not part of the physicists' standard equipment, it nevertheless became a focus of research at DESY. However, the scientists weren't interested in the latest colour trends; they were investigating the popular cosmetic product's composition. In an industrial partnership, experts from DESY used concentrated X-rays to study how lipstick reacts when it is moved from freezing temperatures to tropical heat.*

The unusual experiment was part of the EU-funded Science Link project, which is managed by DESY. Science Link is targeted at industrial companies from the Baltic Sea region. It aims to familiarise these companies with scientific tools that are otherwise primarily used for basic research: accelerators that generate extremely powerful and concentrated X-rays. This synchrotron radiation is much more intense than the X-rays used in doctors' surgeries and is ideally suited for precisely examining a wide variety of materials.



Graham Appleby at the P02 experimental station, where the tests were carried out. Picture: Lars Berg / DESY

Physicists at the University of Riga brought the managers of Science Link into contact with SIA Dzintars, one of the leading manufacturers of cosmetic products in Latvia. The company had noticed a strange phenomenon: over time, a thin film of oil had formed on some of its lipsticks. Did this mean that the consistency of the makeup changed with temperature? To resolve this mystery, the physicists used one of the world's best X-ray radiation sources, PETRA III, to examine the small beauty helpers that are normally found in women's handbags and cosmetics bags.

"The company wasn't aware of the possibilities of synchrotron radiation," says Graham Appleby, who works at DESY as a researcher for the Science Link project. "We first had to tell them about all the things it can do." When a material sample is examined with intense X-rays, researchers can often detect tiny details in the measurement data. For example, they can find out what kinds of molecules and atoms the material is made of and also determine their position. The lipstick was to be put under the X-ray microscope at varying temperatures.

Lipstick wearers expect the cosmetic product to stay on their lips even in winter when they enter a well-heated room after having spent time outdoors in freezing temperatures. To find out whether extreme changes in temperature would alter the material properties, for their experiments at PETRA III the researchers used a sample holder that could be heated and cooled. They first measured six differently coloured lipsticks at room temperature. Then the scientists cooled the lipsticks to minus 50 degrees Celsius before gradually heating them in five-degree increments to plus 50 degrees. They measured the lipsticks at each of these increments. The results showed that the lipsticks underwent a phase transition whenever their basic ingredient, paraffin, contracted during cooling and expanded again as temperatures rose.

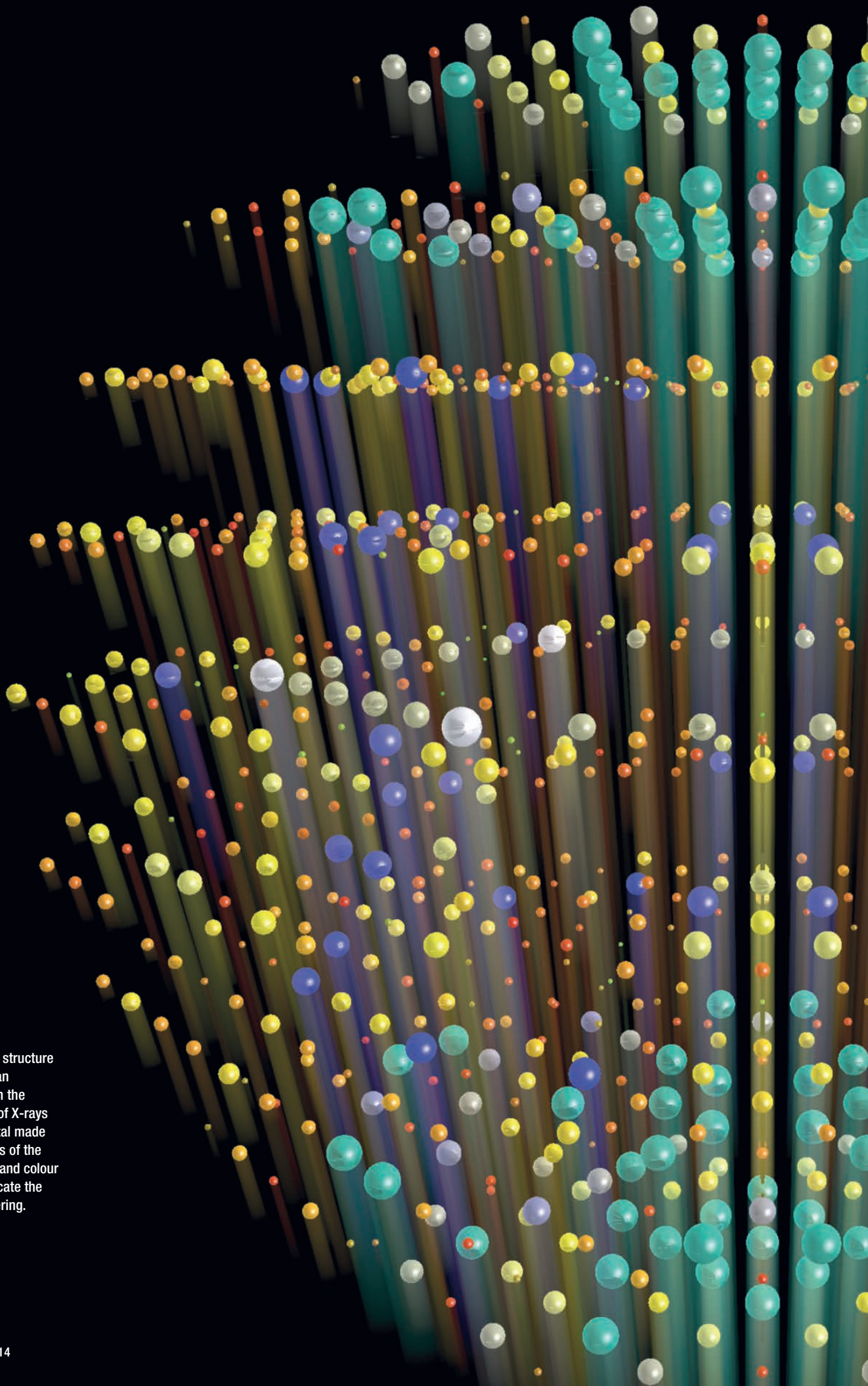
When the experts examined the cosmetic products again at room temperature, they came to a comforting conclusion: the material had regained its original shape, the lipstick was as good as new. Only in one sample that Appleby had heated to 90 degrees Celsius did the material structure change so much that the lipstick became useless. This was good news for Dzintars, because it provided scientific proof that the company's lipsticks are temperature-resistant across an extremely broad range of temperatures extending from minus 50 degrees Celsius to plus 50 degrees Celsius. Further examinations will have to be made with the X-rays from PETRA III before the scientists can arrive at a precise molecular analysis of the oil film and its properties. For the examination of its lipsticks, the cosmetics manufacturer benefited from the many years of experience the scientists have already gathered as they use intense X-rays to analyse material properties. The same technology is used to investigate new high-tech materials such as heat-resistant ceramics for energy-efficient aircraft engines, corrosion-resistant steel for ship propellers and plastic membranes for carbon dioxide capture.

The lipstick test was just one of many studies conducted as part of the Science Link project. Since 2012, 49 companies from the Baltic Sea region have taken advantage of the opportunity to have samples examined with X-rays from a storage ring. The examinations are made free of charge. Among other things, the researchers have investigated the ideal consistency of pigments, optimised energy consumption for a specific fertiliser production technique and studied new catalysts for cleaner chemical processes. Some of the experiments took place at PETRA III in Hamburg, while others were conducted at facilities in Berlin and Sweden. "We were pleasantly surprised that so many companies took advantage of the offer," says Appleby.

SCIENCE LINK

Baltic Sea Region
Programme 2007–2013

Part-financed by the European Union
(European Regional Development Fund)



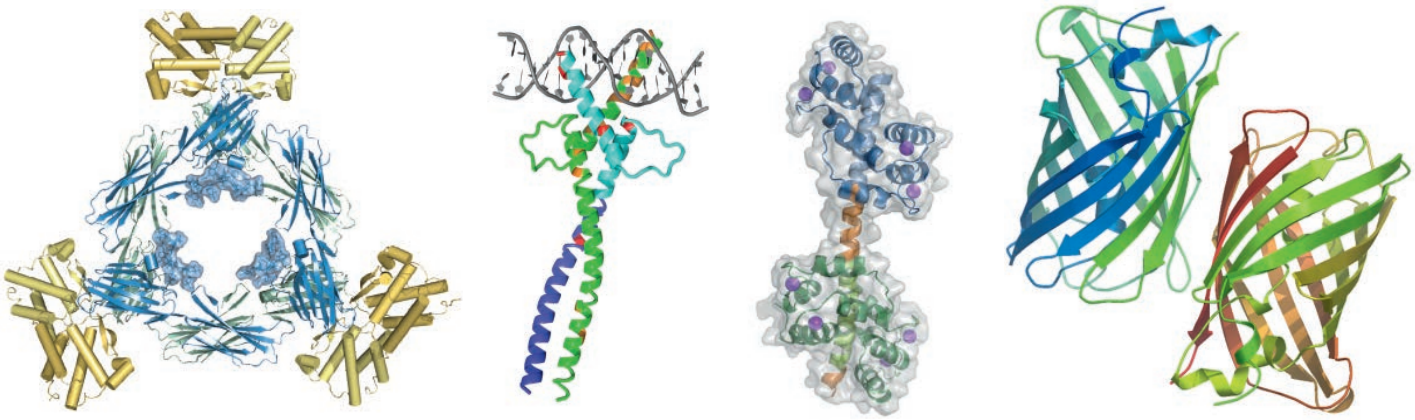
The precise atomic structure of a biomolecule can be determined from the diffraction pattern of X-rays scattered in a crystal made up of large numbers of the molecule. The size and colour of the spheres indicate the extent of the scattering.

SPOTLIGHT

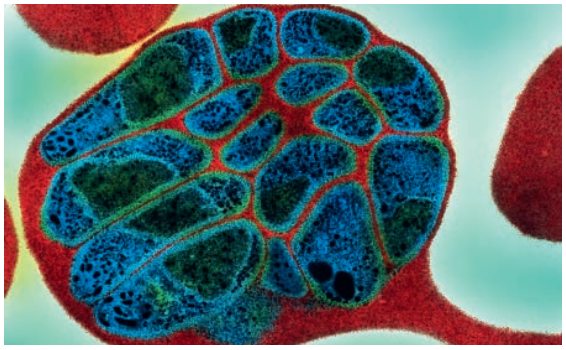
# Infections viewed with X-ray vision

## Structural biology is opening up new paths for developing medications

Infectious diseases are among the world's major scourges. AIDS, tuberculosis and malaria are responsible for millions of deaths throughout the world, newly occurring viruses are a threat to international commerce and antibiotic-resistant bacteria are causing patients to fear hospital stays. That's why it's becoming increasingly important to combat infectious diseases effectively. Physical methods such as structural analysis by means of X-ray radiation can help: researchers can use X-rays to examine viruses, bacteria and parasites at the molecular level in order to decipher their attack mechanisms and design customised medications to use against them.



Malaria is an insidious killer. The pathogen entrenches itself in the host's red blood cells and multiplies there until these cells burst and flood the host's body with new parasites. Every 45 seconds, a person somewhere in the world dies of malaria. And in alarming news from Asia, doctors have reported the first cases of resistance to one of the most important medications against malaria, artemisinine.



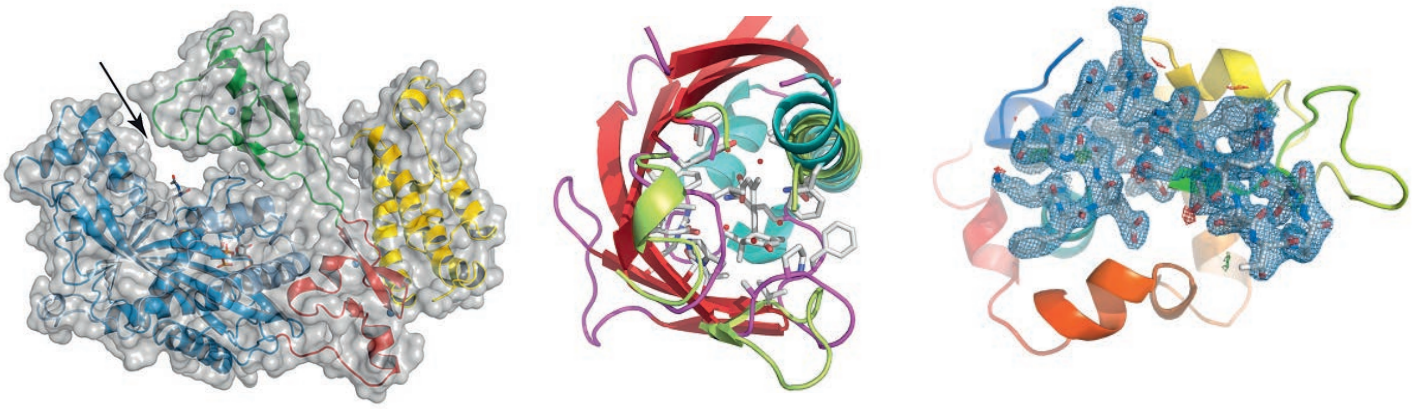
The malaria parasite *plasmodium* (blue) attacks human red blood cells (red). Picture: Moredun Scientific LTD / Science Photo Library

It's therefore high time for us to try to understand the molecular processes of a malaria attack more precisely so that we can find points of attack for new medications. This is exactly the approach taken by structural biology, a comparatively young discipline in the life sciences. With its help, researchers are investigating the detailed atomic structure of proteins, enzymes and hormones, and using their findings to determine the precise characteristics and functions of these biomolecules.

"For example, how does the malaria parasite enter red blood cells?" asks biochemist Chris Meier from the University of Hamburg to illustrate a typical research issue. "This is an extremely complex process involving not just one but many proteins, and we still don't know enough about it." Meier has been closely involved in the establishment of the new Centre for Structural Systems Biology (CSSB) on the DESY campus, which is borne by nine institutions and is devoted to researching infectious diseases at the molecular level.

Biologists who investigate such fundamental processes often use physical methods. The most important tool of structural biology is currently synchrotron radiation, which is generated in particle accelerators. This intense X-ray radiation makes it possible to see the atomic structure of a wide variety of materials, including biological macromolecules.

However, using this tool is not a simple matter. To obtain a sufficiently strong measurement signal, the structural biologists must first crystallise their samples. The resulting protein crystal diffracts the X-ray radiation in a characteristic way, in which reflections from the same grid points of the crystal are amplified. The atomic structure of the



**Protein structures:** They look like tiny works of art, but in these images scientists recognise the precise spatial structures and functions of biomolecules. High-performance computers and special analysis software calculate such molecular structures from the complex diffraction patterns that protein crystals generate when irradiated with X-ray radiation. Pictures: EMBL, Hamburg; CFEL-DESY

molecule can ultimately be computed from the measured diffraction pattern. "It's a kind of mathematical magnifying glass," says DESY researcher Cornelius Gati to explain the process, which was established a century ago by the German X-ray pioneer Max von Laue and the British physicists William Henry Bragg and William Lawrence Bragg.

Calculating the molecular structure on the basis of the diffraction pattern is also no trivial undertaking. That's because, as a rule, biomolecules consist of thousands or even millions of atoms and generate correspondingly complex patterns. However, thanks to increasingly sophisticated mathematical techniques and especially to increasingly powerful computers, researchers have already deciphered the structure of approximately 90 000 biomolecules in the past 50 years. These molecules include not only small ones such as insulin but also gigantic ones such as the ribosome, the protein factory in biological cells.

There is a problem with this method: many proteins can hardly be forced into a crystalline form because they are designed for the liquid media in which biological processes take place. In many cases, researchers can already be glad if they have successfully grown micrometre-small crystals. The smaller the crystal, the more intense the X-ray radiation has to be. As a result, modern crystallography uses X-ray sources that are fed by huge particle accelerators. Electrons leaving the accelerator at almost the speed of light fly through a slalom course marked off with magnets and emit synchrotron radiation in every curve. This generates a brilliant beam of X-ray radiation that enables researchers to investigate even microcrystals.

This method was recently used by a group headed by Inari Kursula from the Helmholtz Centre for Infection Research (HZI) to decipher two important proteins of the malaria parasite. These two variants of the structural protein actin give the *plasmodium* parasites their mobility and thus play a significant role in the infection of human cells. Actin is one of the most frequently occurring proteins in nature; it is crucial to muscular movement and occurs in various forms in almost all living organisms.

## How does the malaria parasite enter red blood cells?

However, the two actin variants of the malaria parasite are clearly different from those found in other living creatures. According to Kursula, "We now understand that the actin filaments of the *plasmodium* parasites are very different from other actin filaments, such as those of human beings, and that they have a completely different structure."

This knowledge could help researchers design customised malaria medications in the future.

X-ray structural analysis has also helped researchers at the U.S. National Institute of Allergy and Infectious Diseases (NIAID) to develop a customised vaccination candidate against the respiratory syncytial virus (RSV), which is the world's most frequently occurring cause of acute respiratory infections in infants and toddlers under the age of three. About 160 000 children die of this infection every year. The scientists had identified the precise atomic structure of the F-protein, which helps the virus penetrate human cells. Plans now call for an artificially produced, harmless form of this protein to be used as a vaccine to prepare the human body's own immune system for attacks of this kind.

## A vaccine against respiratory infections in infants

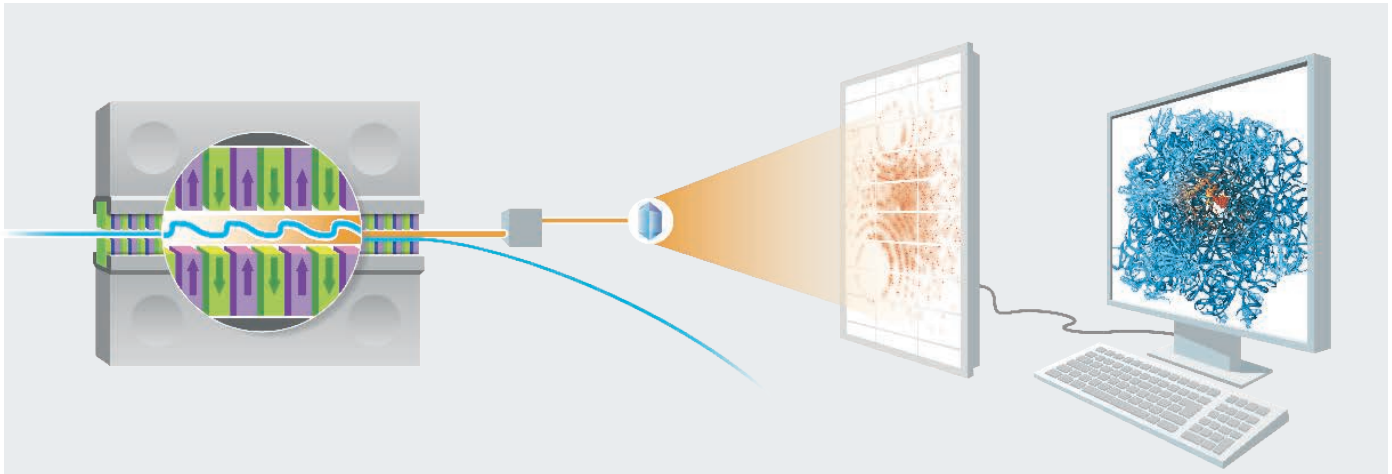
The synthetic vaccine, which was shown to be promising in tests with animals, was named one of the ten most important scientific achievements of last year by the U.S. journal *Science*. According to the article, after decades of hope, structural biology has thus proved its value for vaccine development. Many researchers now hope this work will also point the way towards the development of tailor-made vaccines against other viruses, such as the pathogens causing hepatitis C, dengue fever and West Nile fever, which have so far also been supremely successful at resisting the attacks of the human immune system.

### Customised active ingredients

"There are always new revolutions," says Matthias Wilmanns, director of the Hamburg outstation of the European Molecular Biology Laboratory (EMBL). "There's a lot of enthusiasm." In the past year alone, EMBL researchers have used the tools of structural biology to, among others, expose the attack mechanism of a certain herpes virus, decode a key molecular switch for skin cancer and find a turbo button for the cells' internal calcium pump. All of these discoveries harbour potential for new tailor-made active ingredients.

One example is tuberculosis, whose bacteria have developed a dangerous level of resistance to even second- or third-line antibiotics in many regions. "At DESY, we've been able to identify the structures of about 50 proteins of this bacterium so far," says Wilmanns, who is also the founding director of the new Centre for Structural Systems Biology (CSSB) in Hamburg. "Some of them could serve as possible target points for future medications that attack the pathogens selectively while sparing other useful bacteria."

This is why the pharmaceutical industry is also counting on structural biology. "Discovering and



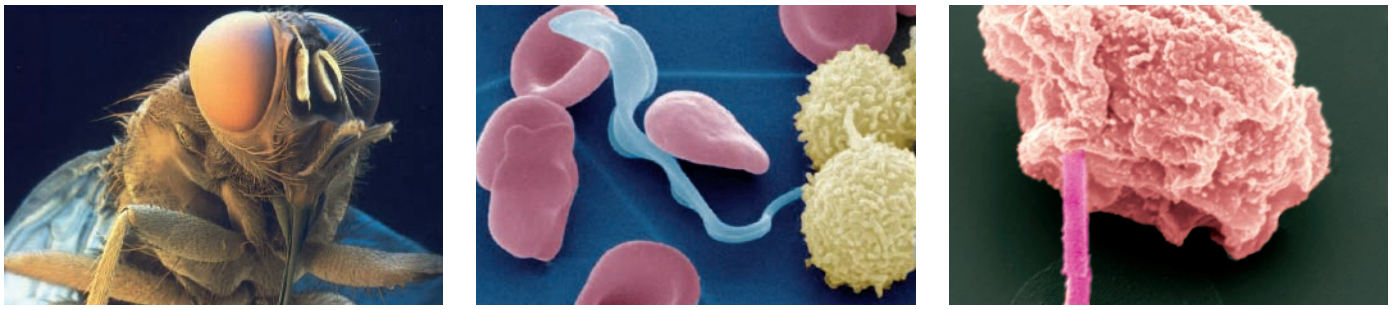
**Structural analysis of biomolecules with X-ray radiation:** Fast electrons (blue) from a particle accelerator are sent into an undulator (left) equipped with powerful magnets (green and violet). The electrons race past the magnets in a slalom pattern. In the process, the particles emit high-energy X-ray radiation (orange), which is directed through X-ray optics at a crystal (centre) made up of biomolecules. The crystal diffracts the X-ray radiation, thus generating a characteristic diffraction pattern on the detector (right). On the basis of this diffraction pattern, the structure of the biomolecules under investigation can be calculated down to the last atom (far right). Illustration: Cyprian Lothringer / DESY


**A real racer:** The FLASH free-electron laser accelerates electrons to high speeds and uses them to generate ultrashort X-ray laser flashes. Picture: Heiner Müller-Elsner / DESY

developing a new medication that is safe and effective is one of the biggest challenges of biomedicine," says Siegfried Throm, managing director for research, development and innovation at the German Association of Research-Based Pharmaceutical Companies (vfa). "The more concrete facts can be gained about the pathogens or the body's own molecules that are relevant to the illness, the less pharmaceutical researchers depend on trial and error."

Among the first medications that were customised using structural biology to attack a certain target molecule were the protease inhibitors against the AIDS pathogen HIV, which were developed in the 1990s. "Today, observing the target structure at the atomic level is part of the standard repertoire of active-ingredient inventors," Throm explains. "For example, structural biology has enabled us to understand why tumour cells become resistant against cancer medications through certain protein mutations, and how we can devise new medications in ways that enable them to ignore such mutations."

Nonetheless, the association emphasises that structural biology cannot provide a uniform blueprint for new medications. "Medications have to fulfil many different requirements simultaneously before you can use them to treat patients safely and effectively," says Throm to dampen excessive expectations. "Having the desired effect at the target site is only one requirement among many. For example, the active ingredients must be able to reach the target organ in the body after the tablet has been consumed without first being broken down in the liver. On the other hand, the active ingredients should not become concentrated in



**Tsetse fly attack:** The bite of the tsetse fly (left) transmits the parasite *trypanosoma brucei* (centre), which causes the severe sleeping sickness. The enzyme cathepsin B offers a promising starting point for developing a potential medication against the parasite. To decipher its structure by means of X-ray radiation, researchers coaxed living insect cells into generating crystals of the enzyme (right). The enzyme crystal looks like a pink rod sticking out of the cell. Pictures: Michael Duszenko / University of Tübingen

the body. They should influence as few additional molecules in the body as possible besides the target molecules, and so on."

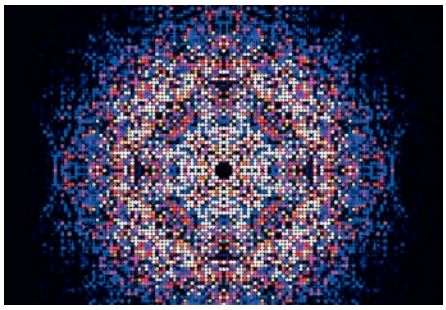
### The Achilles heel of sleeping sickness

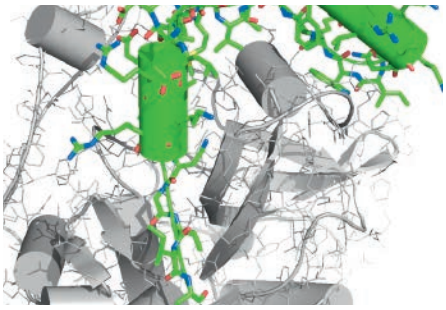
The path to a practicable medication is still a long one, though structural biology can reveal potential starting points. However, it's sometimes impossible to cultivate microcrystals that are large enough to be analysed at a synchrotron. In such cases, even stronger X-ray sources must be used, and here structural biologists place their hopes in X-ray lasers – innovative devices that are also fed by high-performance particle accelerators and deliver extremely brilliant and ultrashort X-ray flashes. Together with its international partners, DESY is now building the world's most advanced X-ray laser, the European XFEL. These facilities are known as free-electron lasers (FELs), because free-flying electrons generate flashes with laser characteristics.

## Ultrashort light flashes from the X-ray laser

These flashes are so intense that every crystal in their way immediately evaporates. But before a crystal disintegrates, it divulges its inner structure: its characteristic diffraction pattern can be recorded before it breaks up. This is how scientists from Hamburg working at what is currently the world's strongest X-ray laser facility, the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory in California, discovered an Achilles' heel of the sleeping-sickness pathogen. Their detailed analysis has delivered the blueprint for a potential medication against the *trypanosoma brucei* parasite, which is a health risk for more than 60 million people, especially in southern Africa. By means of a customised molecular plug, one of the parasite's vital enzymes could be blocked. "This is the first new biological structure to be deciphered at a free-electron laser," emphasises Henry Chapman, a DESY researcher from the Center for Free-Electron Laser Science (CFEL).

Sleeping sickness, whose scientific name is human African trypanosomiasis (HAT), is transmitted through the bite of the tsetse fly. The *trypanosoma brucei* parasites hide within the host's central nervous system, and if left untreated the infection is usually fatal. The illness is generally treated with anti-parasite medications, but these have been developed without a precise knowledge of the biochemical connections involved. As a result, these medications are less safe and reliable than one could wish, according to the scientists. In addition, more and more parasites are developing resistance to the medications. New





The researchers generated X-ray diffraction images from crystals of the enzyme cathepsin B. When put together, almost 200 000 such images create a combined intensity chart (left) that can be used to calculate the three-dimensional molecular structure of the enzyme (right). Pictures: Karol Nass / CFEL-DESY

active ingredients that kill the parasites selectively without affecting the patient's organism would therefore be extremely useful.

## A promising starting point

The researchers on the team of Chapman, Christian Betzel from the University of Hamburg and Lars Redecke from the Laboratory for Structural Biology of Infection and Inflammation, which is jointly operated by the universities of Hamburg and Lübeck, investigated the parasite's enzyme cathepsin B in crystallised form with the intense LCLS X-ray flashes. "In previous tests, this enzyme had proved to be a promising starting point for a medication," Redecke explains. "Blocking the enzyme in the parasites was able to heal the infection in mice."

Unfortunately, the same enzyme can be found in human beings – as in all mammals, in fact. Blocking it non-specifically can have severe consequences for the patient as well. But thanks to their X-ray investigations, the researchers have now discovered characteristic differences between the molecular structure of the enzyme in human beings and in the parasite. This basically opens up the possibility of blocking the parasite's enzyme selectively with a customised molecule, while leaving the patient's enzyme intact.

The researchers took an innovative approach. They allowed living insect cells to produce the enzyme crystals in vivo. In the usual crystallisation process, bacteria produce the desired biomolecule, which is then crystallised into the largest possible units in the laboratory with a great deal of waste. In this case, the in vivo technique, which was developed in the laboratories of Betzel and of Michael Duszenko at the University of Tübingen, was the only process that could produce usable crystals.

## Useful helpers in the lab: insect cells produce enzyme crystals

Moreover, the in vivo crystallisation in insect cells had a further crucial advantage. In the process, the cathepsin B was "frozen" in its natural configuration. The enzyme operates like a pair of molecular scissors that divides other proteins. It is therefore produced in the organism in an inactivated form in which a small protein molecule called a peptide blocks the scissors. The cell activates the enzyme and releases the peptide only when the scissors are actually needed.

"Thanks to the coupled peptide, we were able to look beneath a previously inaccessible structural area of the cathepsin," explains Betzel. There, the analysis revealed clear differences between the peptide binding sites in

the parasite and in human beings. These differences can be used to make a customised artificial inhibitor that selectively blocks the parasite's enzyme.

"In this way, nature provided us with a basic blueprint telling us what an artificial inhibitor for the parasite's enzyme could look like," he adds. Nonetheless, the scientists emphasise that in spite of this promising start, a possible new medication is still very far in the future.

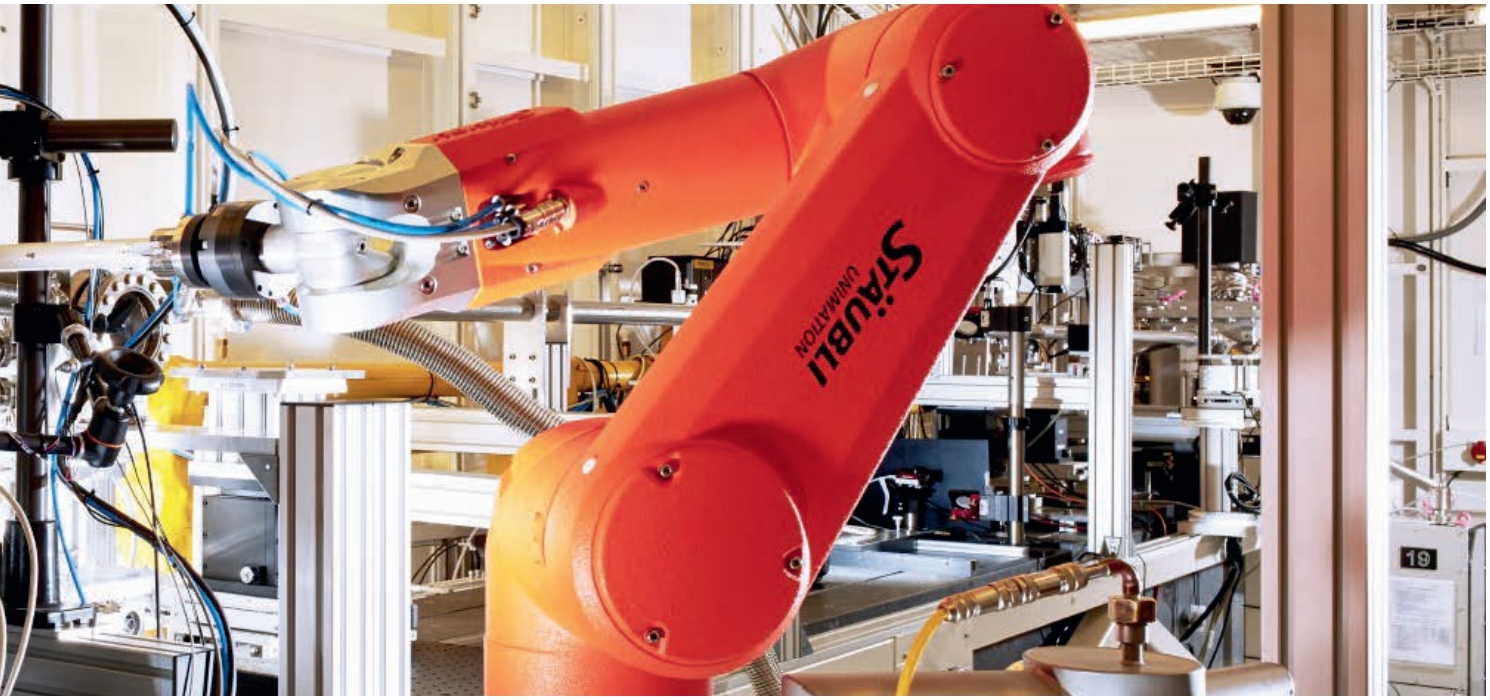
## A concerted attack against infections

The example of sleeping sickness illustrates the systematic approach taken by structural biology. Infectious diseases are the special focus of the new Centre for Structural Systems Biology (CSSB) on the DESY campus, which nine major German research institutions have joined together to operate: the Helmholtz Centre for Infection Research, the Bernhard Nocht Institute for Tropical Medicine, the Heinrich Pette Institute for Experimental Virology, the University of Hamburg, the University Medical Center Hamburg-Eppendorf, Hannover Medical School, Forschungszentrum Jülich, EMBL and DESY.

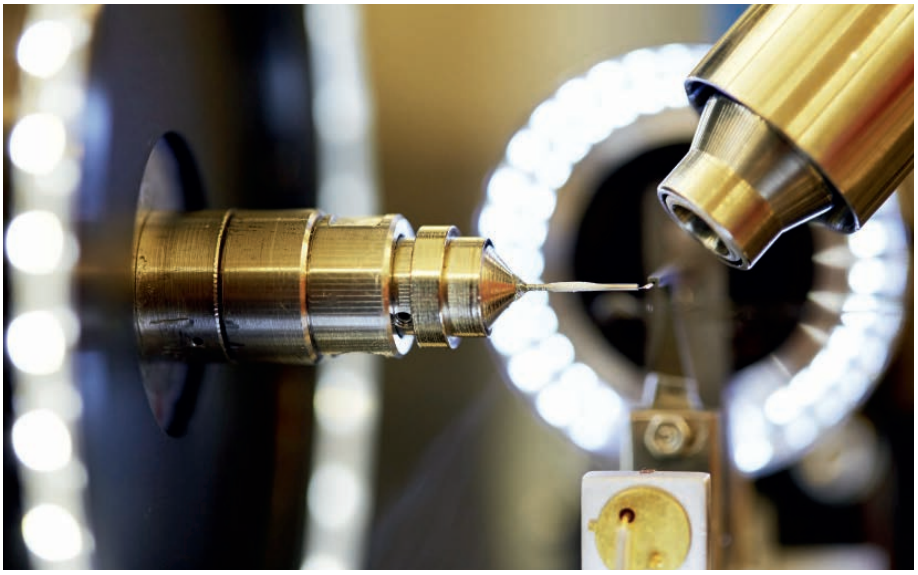
In the new centre, research will focus on deciphering the interplay of proteins in medically relevant infections caused by viruses, bacteria or parasites. The work will be interdisciplinary. Physicists, biologists and medical researchers will work together across professional and institutional boundaries under the overarching roof of the CSSB to pursue new approaches to research.

**"Under the overarching roof of the CSSB, we are generating promising approaches to research across professional and institutional boundaries."**
DESY director Helmut Dosch

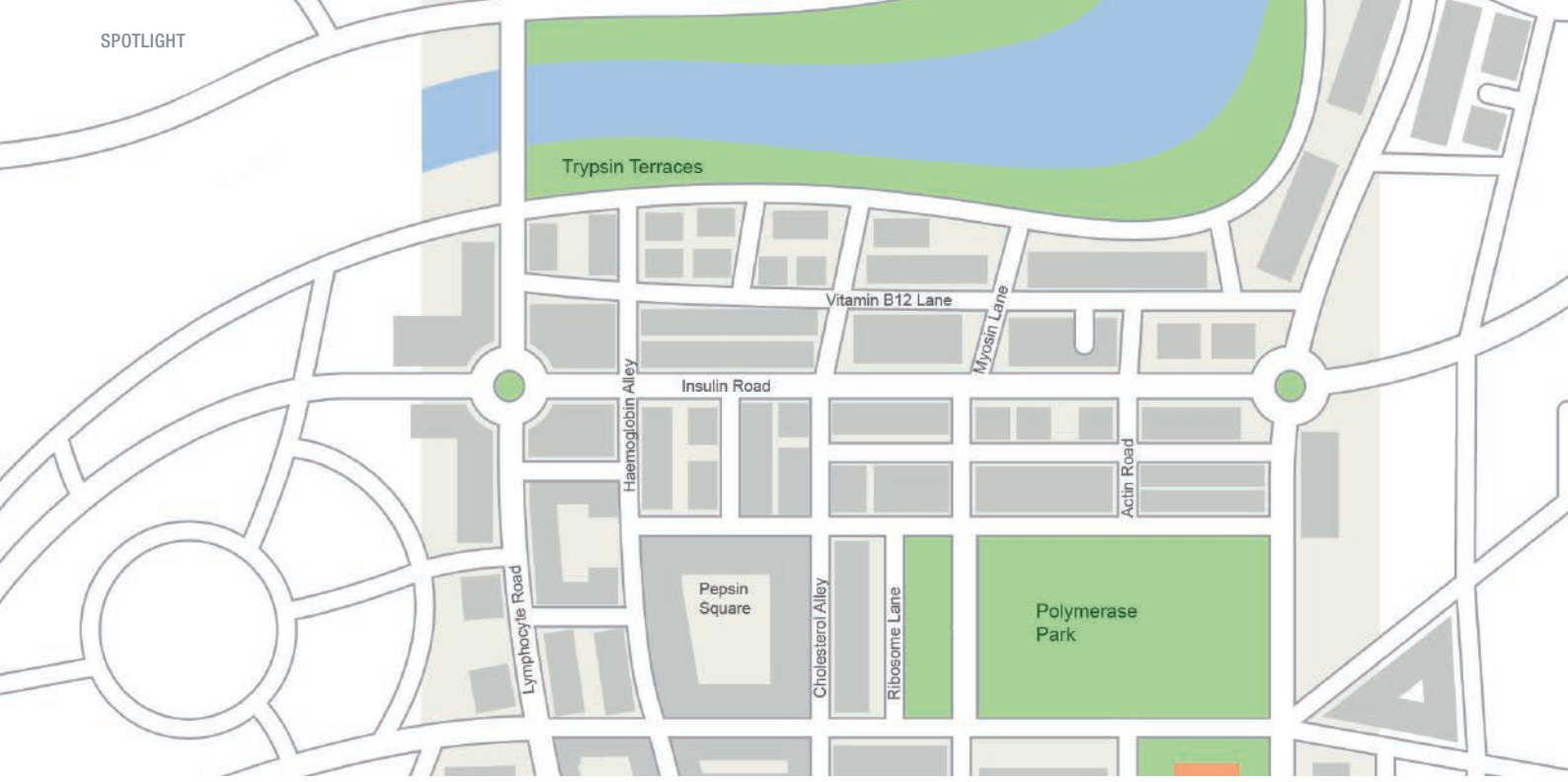
The CSSB benefits from the close proximity of the X-ray radiation sources at DESY. In addition, it is being equipped with a high-performance electron microscope, a further important tool of structural biology. "This versatile combination of investigation methods can't be found anywhere else in the world," says biochemist Chris Meier, who headed the task force that set up the new centre. "The CSSB will take infection biology a crucial step further," Meier asserts with confidence.







**X-rays for proteins:** The P11 beamline at DESY's X-ray radiation source PETRA III was specially designed for diffraction experiments with biological samples (top). The sensitive protein crystals are cooled with liquid nitrogen (above left) and positioned on a sample holder (left) exactly within the intense X-ray beam. Pictures: Heiner Müller-Elsner / DESY




# "Google Maps for the human body"

**State-of-the-art sources of X-ray radiation offer the possibility of deciphering the atomic structure of biomolecules and pathogens and thus systematically investigating their respective functions. This capability is giving biological research a new quality, explains Matthias Wilmanns from the European Molecular Biology Laboratory (EMBL). Wilmanns is one of the initiators and the founding director of the Centre for Structural Systems Biology (CSSB), which is currently being set up by nine partners on the DESY campus in Hamburg.**

femto *What's happening in structural biology?*

Wilmanns We're all familiar with Google Maps and similar offers. We are operating something like Google Maps for the human body. After all, people have a basic interest in being able to zoom into the human body as precisely as possible. A hundred years ago, we had light microscopy for this purpose, and today, we've got X-ray structural analysis. Thanks to this method, we can now see individual atoms. That's a milestone.

*In other words, with the help of X-ray radiation, you are decoding the atomic structures of a biomolecule and thus learning something about its function?*

Wilmanns Yes, that's exactly how it works. And if you look at the textbooks of today, you'll see that they're full of our research findings in structural biology. That's even true of schoolbooks. In these books, there are images of complex biomolecules that it wasn't possible to capture for the books I used during my schooldays. There has been a genuine increase in knowledge.

Matthias Wilmanns heads the outstation of the European Molecular Biology Laboratory (EMBL) at DESY. Pictures: Lars Berg / DESY

*Does this technology also have practical applications?*

Wilmanns It's being used to explore new paths in medication research, for example. We have about 30 000 proteins in our bodies. The simplest idea for a medication is that I selectively block one of these proteins with a small, customised molecule that has exactly the right shape. This is often called the "lock and key" principle, which is only a two-dimensional model. In actuality, it's more like a three-dimensional map that has mountains, valleys, craters, caves and much more. And the more familiar we are with these valleys, mountains and caves, the better we can tailor something to fit on them. The more we know about these structures, the less we have to use trial and error. Instead of using the traditional procedures of pharmaceutical research, which are often extremely expensive, we can take shortcuts and save millions of euro.

*Will we soon have a customised medication for every ailment?*

Wilmanns In any case, structural biology has given biological research a new quality. But we have to be realistic. We won't be able to solve all the problems of medication development overnight. That's because, unfortunately, many illnesses are terribly complicated – especially infectious diseases, which are my research area. It's simply not always the case that only one certain molecule is involved. In many cases, there are even hundreds of molecules that interact and cause something. You might reach the snap conclusion, 'I've now found an interesting molecule; I'm going to try to block it.' But then you realise that it interacts with other molecules near to it, those molecules in turn interact with others, and so on.

*All the same, structural biology offers the possibility of systematically addressing this kind of problem. How did this used to be done?*

Wilmanns The traditional method that was used 50 or 100 years ago and is still sometimes used today consists of producing or extracting masses of small molecules, for example from tropical plants, and trying them out on models of organisms and diseases. Finally, the researchers look at what effects the substances have had. This method is called the "phenotypic approach". However, it's basically a refined type of alchemy.

*X-ray crystallography, which is being used today to decipher many of these biological structures, is certainly not a new technology. Why is it only now that structural biology is developing so rapidly?*

Wilmanns The method of crystallography has existed for over a century. But the element that was missing for a long time was the computer. It's that simple. We didn't have the necessary tools to evaluate the data in the complexity that was required to do structural biology. What we've seen in the last 20 or 30 years is a huge increase in the number of deciphered structures, ranging from relatively simple proteins such as insulin and lysozyme,

which have comparatively few atoms – whereby even the simple biological macromolecules are very complicated – to the ribosome, for example, which was decoded with the help of facilities including those at DESY. The ribosome has a molecular mass of three megadaltons – in other words, several hundred thousands of atoms. That's a huge number. When I was writing my doctoral thesis in the 1980s, we dreamed of finding out the structure of the ribosome. Back then, I guess no one imagined it would become possible so soon.

*So the rapid development of computer technology paved the way for structural biology?*

Wilmanns Synchrotron radiation was also a major revolution. At the end of the 1960s and the beginning of the 1970s, Ken Holmes and Hugh Huxley used synchrotron radiation for the first time on biological samples at the DESY ring. Since that time, there has been a rapid development of radiation sources. And of course it's a pleasure to see that Hamburg, thanks to DESY's PETRA III storage ring, is still at the cutting edge today.

*And this development is far from over.*

Wilmanns The next revolution with respect to radiation is the X-ray laser – for example, the European XFEL, which is now being built and will extend from the DESY campus in Hamburg-Bahrenfeld to the neighbouring town of Schenefeld. At the moment, such lasers exist only in Stanford, California, and in Japan. When we look at them and the work achieved at them today, it's clear that they will enable us to move forward into completely new dimensions.

*What role is the CSSB planning to play in this development?*

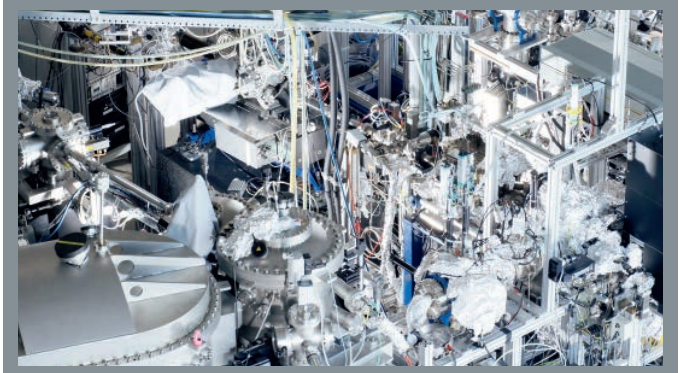
Wilmanns When we got together for the first time in 2004, our basic idea was: We've got a fantastic infrastructure here in Hamburg – which was true back then already – and we want to complement this infrastructure by recruiting top researchers locally, right here. That was the basic idea behind the CSSB. Our goal is to work on a par with the leading global research institutions in the field. There are only a handful of them. And the combination of CSSB, PETRA III and European XFEL is unique in the world.

# FEMTOPOLIS

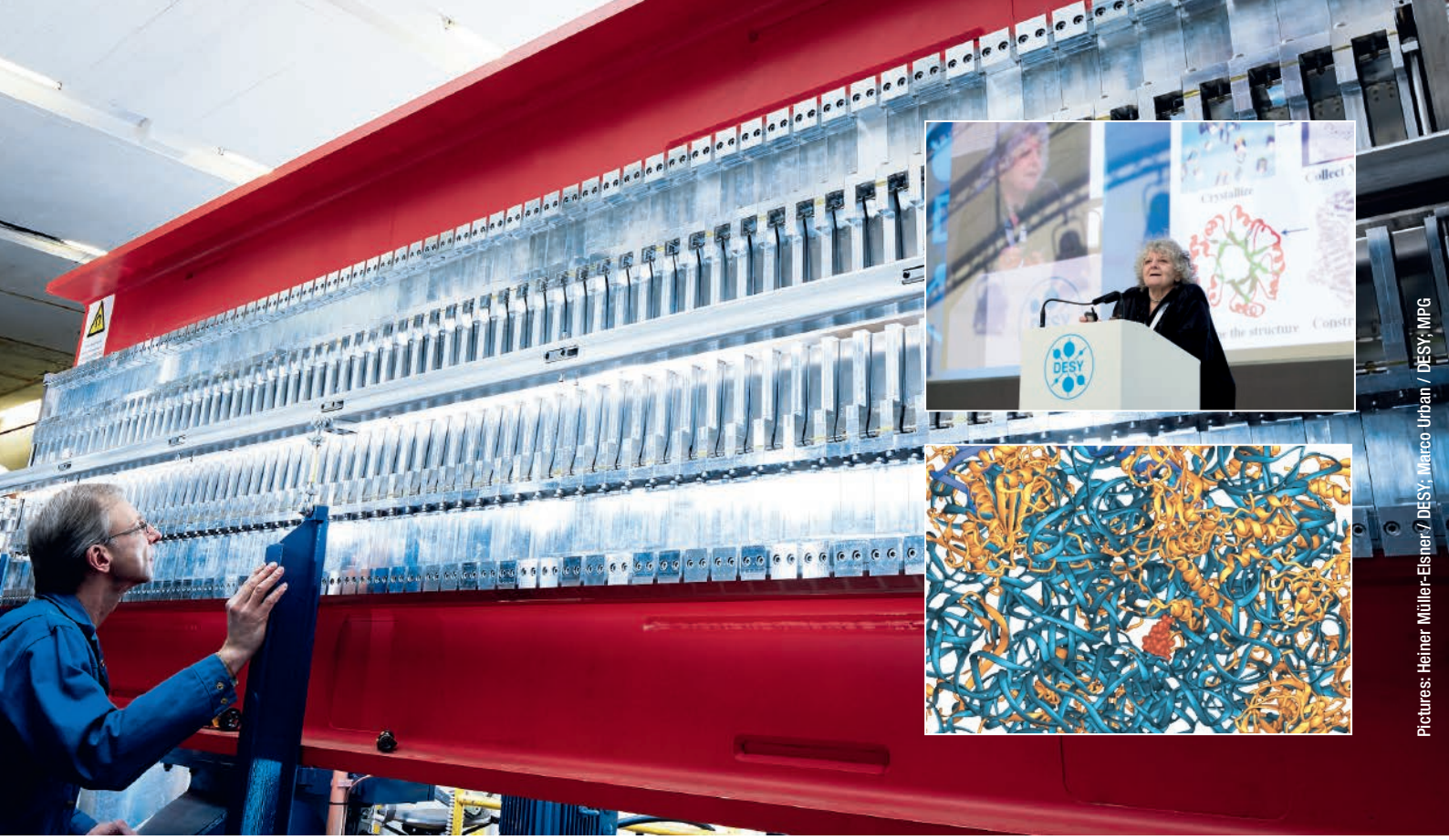
## No high tech without aluminium foil

Who came here, unwrapped his lunch sandwich and wadded the aluminium foil around the experiment? Nobody, fortunately – because eating is not allowed in the experimental hall of FLASH, the free-electron laser at DESY in Hamburg. The particle accelerator produces intense ultrashort X-ray laser flashes, which travel through beam pipes to the measuring stations to illuminate various samples at the atomic level. To make sure the light-speed laser flashes are not disturbed by unwanted particles, an almost perfect vacuum has to prevail in the beam pipes. This requires the removal of not only air but also water molecules and residual gases that have accumulated on the interior surfaces of the metal pipes. Heating elements wound around the pipes are used to evaporate these impurities. And that's where the aluminium foil comes in. It insulates the entire structure and ensures that the heat develops its effect inside the pipes rather than escaping into the hall. As a result, the vacuum pumps can operate optimally and provide a smooth flight path for the light particles.

The crumpled wads of aluminium foil that look like rubbish are actually crucial components of the high-tech measuring stations of ultramodern X-ray radiation sources!



Aluminium foil ready for action in the experimental hall of FLASH
Picture: iStockphoto; Heiner Müller-Elsner / DESY




Pictures: Heiner Müller-Elsner / DESY; Marco Urban / DESY; MPG

# It began with a muscle

Special magnet structures known as undulators (large photo) generate the intense X-ray light, which was also used by Nobel Prize laureate Ada Yonath (small photo above) to decipher the structure of the ribosome (small photo below).

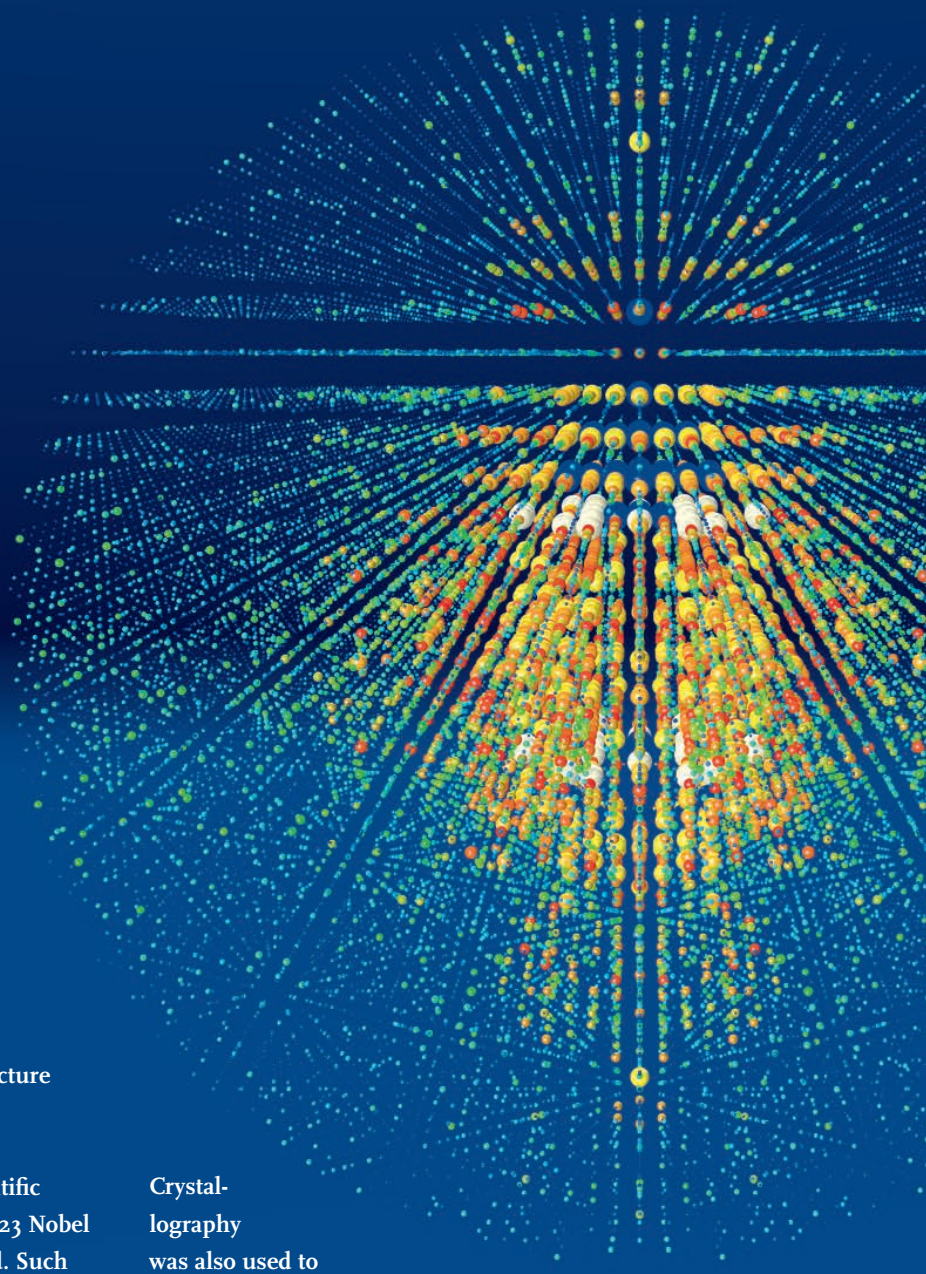
Fifty years ago, researchers began to make measurements at DESY's oldest ring accelerator with a special kind of light called synchrotron radiation. From these humble beginnings, DESY developed into one of the world's leading centres in this field. Today, scientists from a wide variety of disciplines use the intense X-rays from the particle accelerators in Hamburg to look with atomic precision into industrial materials, cultural objects, bone implants, nanomaterials and biomolecules.

The success story of structural biology began at DESY with a muscle. In the summer of 1970, Ken Holmes and Gerd Rosenbaum used synchrotron radiation to make the first diffraction images of an insect's flight muscles. Although the pictures look like blurry splotches compared to today's diffraction images, they were a scientific breakthrough at the time. In the late 1970s, the process enabled scientists to clarify what occurs at the molecular level during muscle movement. To this end, the pioneers of structural biology used the DORIS storage ring, which went into operation in 1974 and gave the young research discipline a big boost.

The particle accelerator's intense, concentrated X-rays proved to be an ideal tool for studying protein structures in detail. Experts from the European Molecular Biology Laboratory (EMBL), the Max Planck Society (MPG) and the University of Hamburg used these X-rays to analyse large numbers of biomolecules and decipher at the molecular level how pathogens attack and exactly where medications could counterattack. At DORIS, biochemist Ada Yonath successfully conducted crucial experiments for clarifying the complex structure of the ribosome – one of the key molecules in living organisms. In 2009, Yonath and two colleagues received the Nobel Prize in Chemistry for this achievement. DORIS was one of the world's leading sources of synchrotron radiation; in the late 1990s, around 15 percent of the protein structures deciphered worldwide had been analysed in Hamburg. Scientists also achieved methodological breakthroughs at the facility. For example, researchers from the EMBL outstation on the DESY campus developed detectors and analysis software for protein crystallography that were both widely successful worldwide.

2014
international year of crystallography

# 2014: the International Year of Crystallography



One hundred years ago, the German X-ray pioneer Max von Laue received the Nobel Prize in Physics for his groundbreaking discoveries regarding the diffraction of X-rays by crystals. His experiments marked the birth of X-ray crystallography, which has produced an impressive spectrum of achievements ranging from fuel-efficient aircraft turbines to new medications and improved microchips. By declaring 2014 the International Year of Crystallography, the United Nations (UN) has put this technology into the limelight. Crystallography now pervades almost all scientific research and is used wherever researchers want to clarify the spatial structure of matter with atomic precision.

The significance of crystallography's scientific accomplishments is demonstrated by the 23 Nobel Prizes that have been awarded in this field. Such "X-ray vision" is indispensable for deciphering the structure and function of biomolecules, for example. By discovering that enzymes can be crystallised, the American chemist James B. Sumner paved the way for the structural biology of today. In 1946, he received the Nobel Prize in Chemistry for this discovery.

Between 1920 and 1960, X-ray crystallography helped researchers determine the structures of a variety of key biological molecules, thus contributing to major medical advances. For example, the British scientist Dorothy Hodgkin deciphered the structure of cholesterol, penicillin, vitamin B12, insulin and other substances. In 1964, she was awarded the Nobel Prize in Chemistry.

Crystallography was also used to reveal the structure of complex molecules. For example, the British scientists Max Perutz and John Kendrew deciphered the structure of oxygen-binding haemoglobin, a feat for which they received the Nobel Prize in Chemistry in 1962. In 2012, the prize was awarded to Robert Lefkowitz and Brian Kobilka from the USA for unveiling the inner workings of an important family of cell receptors that control almost all of the functions of the human body.

"Over the past 50 years, crystallographers have unveiled the structure of more than 90 000 biomolecules, leading to far-reaching consequences for healthcare," says Irina Bokova, director general of the United Nations Educational, Scientific and

This image, which combines the information from 15 000 measured diffraction patterns, was used to decipher the structure of the photosystem I protein complex.
Picture: Thomas White / CFEL-DESY

Cultural Organization (UNESCO), which is helping to organise the scientific year's events. Crystallography tasks used to be very time-consuming; it took Perutz 20 years (including interruptions) to decipher haemoglobin, for example. These tasks are now daily routine for many researchers. Sophisticated algorithms help scientists to determine the molecules' structures from complex diffraction patterns. What's more, today's X-ray detectors are much faster than those used in Perutz' day.

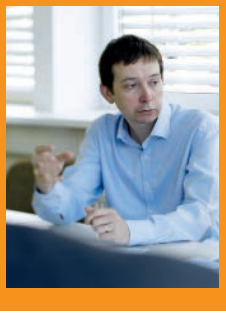
The biggest improvement, however, is that researchers no longer depend on using X-ray tubes. Thanks to synchrotron facilities, scientists now have access to radiation sources that are many orders of magnitude more powerful than those used in the past. And the next generation of X-ray sources, the free-electron lasers, is now ready for use. Free-electron lasers generate ultrashort X-ray pulses that are much brighter and much more concentrated than the radiation produced by synchrotrons.

International Year of Crystallography:
www.iycr2014.org
www.iycr2014.de

## One hundred years after its invention, is crystallography now obsolete, Mr Chapman?

**Henry Chapman is a professor at the Center for Free-Electron Laser Science (CFEL), where he evaluates the potential uses of state-of-the-art free-electron lasers, whose X-ray pulses are one billion times more intense than synchrotron radiation.**

**femto** *Mr Chapman, you are one of the pioneers of research at free-electron lasers, which open up completely new possibilities also for deciphering non-crystalline structures. One hundred years after its invention, is crystallography now obsolete?*
**Chapman** Crystallography is still an exciting research field with many pioneering applications. Free-electron lasers give us the opportunity to use tried and tested ideas in new ways in order to investigate the structures of individual molecules, for example.
**femto** *What kinds of molecules, exactly?*
**Chapman** Primarily biomolecules. All biological processes take place in aqueous solutions, where there simply aren't any rigid crystalline shapes. That's why protein crystallography is such a challenge – many biological structures simply cannot be forced into a crystalline straitjacket. However, the analysis of these structures can greatly promote the research of active ingredients in medicine, for example.
**femto** *How far has research progressed in this field?*
**Chapman** We can now use extremely short X-ray pulses to make atomic-resolution images before the intense radiation destroys the biomolecule being studied. That's an important breakthrough. Tiny nanocrystals suffice as samples nowadays, thus minimising the laborious crystallisation process.
**femto** *When will we no longer need any crystals at all?*
**Chapman** We still face several technological challenges. We have to eliminate interfering signals and optimise the detectors. In addition, we are working on positioning individual molecules in such a way that the X-ray beam actually hits them. This requires a kind of aerosol, but the aerosol must not be too dilute, or else the hit rate will be too low.



**femto** *So when will it be?*
**Chapman** I expect it to be in a few years, because new breakthroughs are taking place all the time.

DESY researcher Henry Chapman
Picture: Heiner Müller-Elsner / DESY

## Start-up award for laser project

**Helmholtz spinoff is developing high-power lasers for scientific and industrial use**

A joint spinoff of DESY and the Helmholtz Institute Jena has won the start-up award of the German Competence Networks for Optical Technologies (OptecNet) for the development of high-power lasers for scientific and industrial use. The spinoff in question, Class 5 Photonics, prevailed against 14 first-rate competitors. During the competition's final round at the Optatec trade fair, the spinoff's four physicists won over the judges with their innovative laser technology and an outstanding business model.


Mark J. Prandolini, Robert Riedel and Michael Schulz (from left to right) from the Class 5 Photonics team. Picture: Class 5 Photonics

"From the automotive industry to the medical technology sector, lasers have become a universal tool for working on a wide variety of different materials," explains Michael Schulz from the Class 5 Photonics team. "The shorter the lasers' pulses are, the more precisely you can work with them." DESY researcher Schulz and his colleagues Franz Tavella, Robert Riedel and Mark J. Prandolini from the Helmholtz Institute Jena (a branch of the GSI Helmholtzzentrum für Schwerionenforschung) have developed flexible high-power lasers that generate pulses in the femtosecond range. A femtosecond is one quadrillionth of a second.

To create the flexible femtosecond high-power lasers, the physicists used an innovative technology that is much more compact than existing systems and makes such short pulses at such high power outputs possible at all. The prototype of the new high-power laser has a planned output of 20 watts and measures only 80 by 80 centimetres.

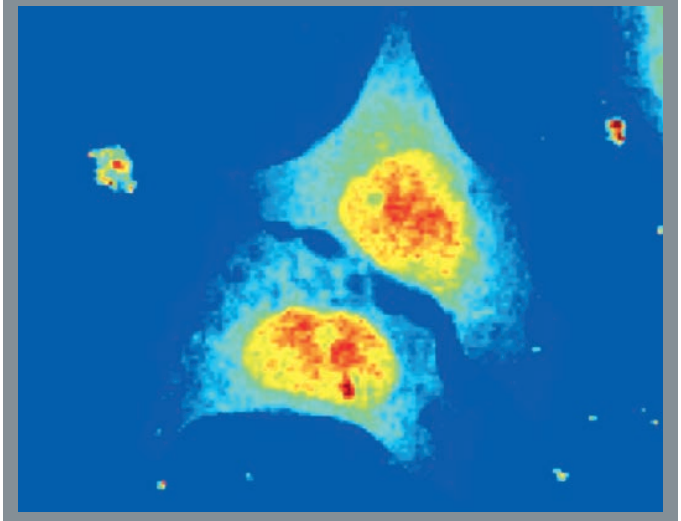
**www.class5photonics.com**

## Researchers X-ray living cancer cells

Göttingen-based scientists working at DESY's PETRA III research light source have carried out the first studies of living biological cells using high-energy X-rays. The new technique shows clear differences between the internal structure of the living cells and that of the dead, chemically fixed cells that are usually analysed. "The new process offers us the first opportunity to investigate the internal structure of living cells in their natural environment using hard X-rays," says the head of the working group, Sarah Köster from the Institute for X-ray Physics at the University of Göttingen.

The scientists used the bright X-ray beam from PETRA III to scan living as well as chemically fixed cells in order to gain information about their internal nanostructure. "Each image was exposed for just 0.05 seconds to avoid damaging the living cells too quickly," explains Michael Sprung from DESY. The results showed that the chemical fixation produces noticeable differences in the cellular structure on a scale of 30 to 50 nanometres (millionths of a millimetre). "Due to the ever-greater resolutions of the various investigative techniques, it is becoming increasingly important to know whether the internal structure changes during sample preparation," says Köster. In future, the new technique will make it possible to study unaltered living cells with high resolution.

**Reference: Scanning X-ray Nano-Diffraction on Living Eukaryotic Cells in Microfluidic Environments; Physical Review Letters, 2014; DOI: 10.1103/PhysRevLett.112.088102**



Cells in X-ray light: Each pixel summarises a complete X-ray scattering diagram. The colour reveals how strongly the X-ray radiation is scattered at the point in question.
Picture: Britta Weinhausen / University of Göttingen

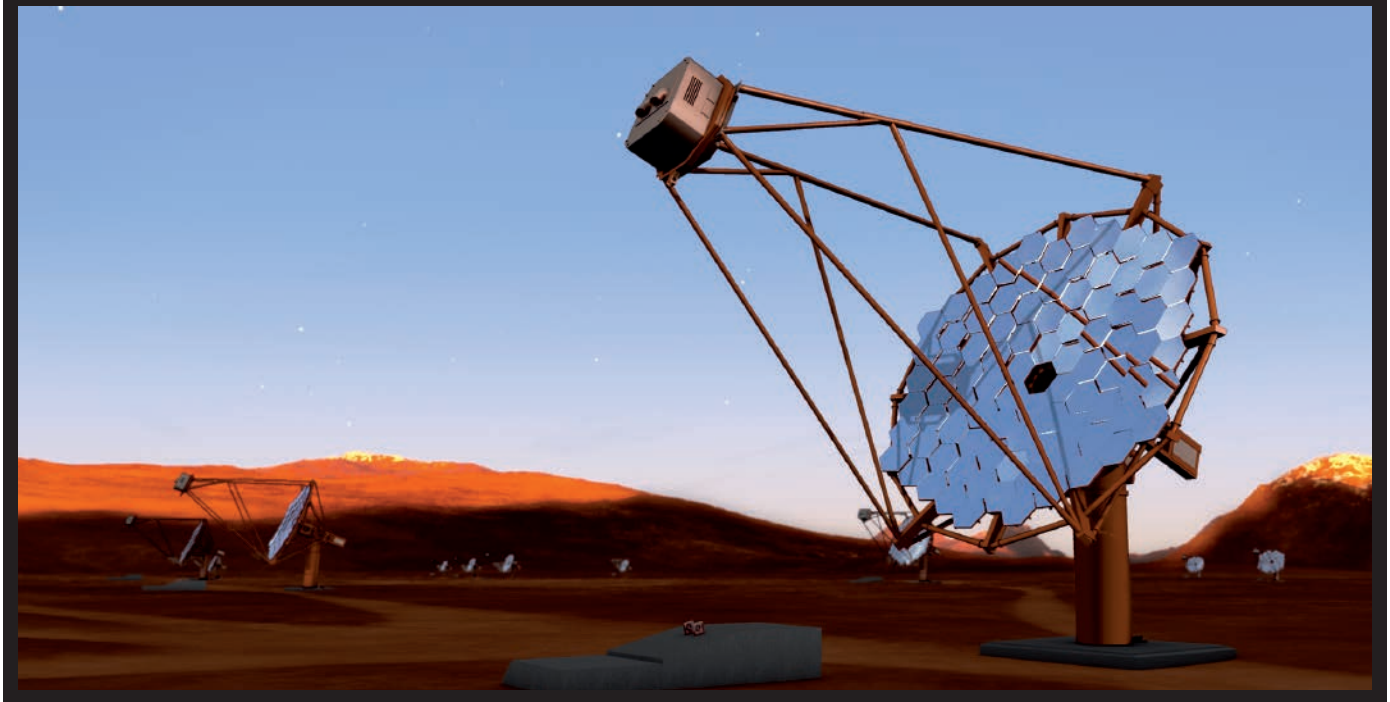
# Measuring device for X-ray laser flashes

Researchers from DESY and the SLAC National Accelerator Laboratory in the USA have developed a new method for measuring the ultrashort flashes of X-ray lasers with previously unattainable temporal resolution. The new technique enabled scientists at the world's strongest X-ray laser, SLAC's Linac Coherent Light Source (LCLS), to achieve a temporal resolution of one femtosecond, or one millionth of a billionth of a second (0.000 000 000 000 001 seconds). The previous record for the analysis of individual X-ray pulses was 10 femtoseconds. The pulse analysis improves the evaluation of measurement results at X-ray free-electron lasers (XFELs). Researchers expect XFELs to open up pioneering new investigation possibilities in a variety of areas, ranging from the imaging of individual molecules to the filming of electron movements in atoms. The ultrashort, high-energy XFEL pulses provide insights into extremely tiny dimensions and ultrafast processes. However, interpreting these measurements is challenging, because the individual XFEL flashes vary in their form and length. The new pulse monitor provides researchers with precision measurements of every individual X-ray flash. This information is crucial for the analysis of data from the LCLS and other free-electron lasers such as DESY's FLASH and the European XFEL, which is currently being built in northern Germany.

Reference: Few-femtosecond time-resolved measurements of X-ray free-electron lasers; Nature Communications, 2014; DOI: 10.1038/ncomms4762

# Site for CTA gamma-ray telescope

The international Cherenkov Telescope Array (CTA) gamma-ray telescope moved a big step closer to its realisation after representatives of 12 partner countries decided to begin negotiations with Chile and Namibia to select the location of the CTA experiment in the southern hemisphere. As a third possibility, the planners are also considering a site in Argentina. "The CTA's location has to be selected soon so that the international project can be quickly constructed," says Christian Stegmann, director of DESY in Zeuthen near Berlin, where the DESY participation in the project is based. "The decision to begin concrete negotiations regarding the larger location in the southern hemisphere has brought the CTA project a big step forward." The Cherenkov Telescope Array is the next major project in the area of astroparticle physics. The project will encompass as many as 100 reflecting telescopes in a field of up to ten square kilometres in the southern hemisphere and a smaller array of about 25 telescopes in the northern hemisphere. Scientists plan to use these telescopes to measure the high-energy gamma radiation coming from outer space in order to collect valuable information about cosmic particle accelerators.

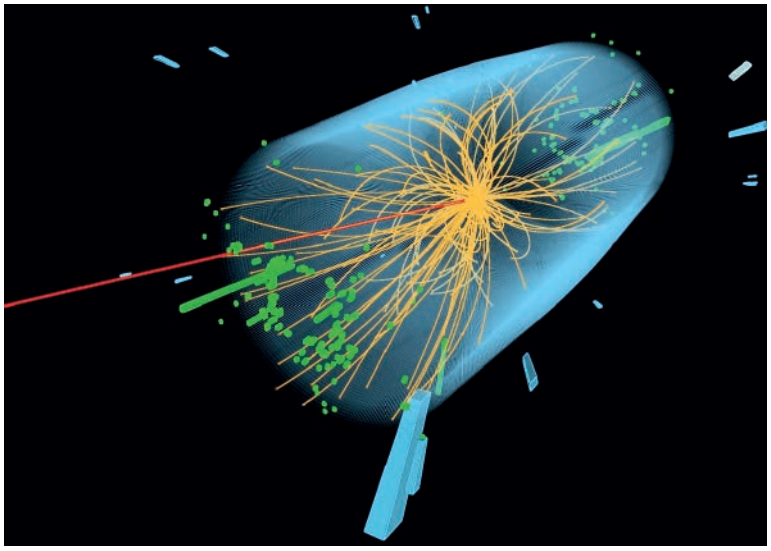


Visualisation of the Cherenkov Telescope Array. Picture: Milde Science Comm. / Exozet / DESY

# News about the Higgs particle

## Decay into heavy leptons confirmed for the first time

The recently discovered Higgs particle sometimes decays into heavy relatives of the electron known as tau leptons, as an international research team at the European research centre CERN near Geneva experimentally verified for the first time. The finding, which was made using the CMS detector at the world's largest particle accelerator, CERN's Large Hadron Collider (LHC), confirms previous predictions regarding the properties of the Higgs particle. In 2012, the researchers involved in the LHC experiments ATLAS and CMS had announced the discovery of a new elementary particle: the long sought-for Higgs boson, which can explain how elementary particles get their mass. "This discovery was a major milestone in physics," says Rainer Mankel, a scientist from the CMS group at DESY. "However, we are continuing our in-depth investigations of the Higgs particle's properties to find out whether they coincide with our theoretical expectations."



In their latest study, the CMS researchers were able to confirm for the first time that the Higgs boson can indeed decay into leptons. Tau leptons are particles that have properties similar to those of electrons, but are 3500 times heavier. The study of the Higgs particle's decay not only confirms the predictions implied by the Standard Model of particle physics, but might also point to the existence of new phenomena that physicists at the LHC are looking for.

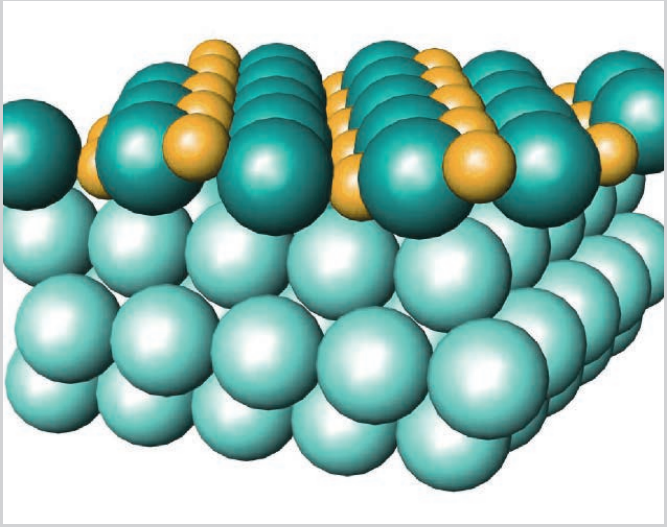
Reference: Evidence for the 125 GeV Higgs boson decaying to a pair of tau leptons, Journal of High Energy Physics, 2014; DOI: 10.1007/JHEP05(2014)104

Recording of a particle collision in the CMS detector of the LHC at CERN near Geneva. Picture: CERN

# Better catalytic converters

A Swedish–German research team used a new X-ray technology to watch a catalytic converter operate in real time and analyse the atomic structure of its surface. The technology, which was developed at DESY's PETRA III X-ray source, will make it possible to design optimised materials, such as improved catalysts, at the atomic level. The technology enables the atomic structure of surfaces to be determined much faster than was previously the case. As a result, it will be possible to record surface reactions such as catalysis, corrosion and growth processes with a temporal resolution of less than one second.

"The new technology enables us to watch surface processes that couldn't previously be observed in real time and that play a key role in many areas of materials science," explains DESY researcher Andreas Stierle. The team of researchers around lead author Johan Gustafson from the University of Lund in Sweden presented the results in the U.S. journal *Science*.



Schematic representation of a catalytic converter's palladium surface. Picture: Johan Gustafson / University of Lund, Sweden

Reference: High-Energy Surface X-Ray Diffraction for Fast Surface Structure Determination; Science, 2014; DOI: 10.1126/science.1246834

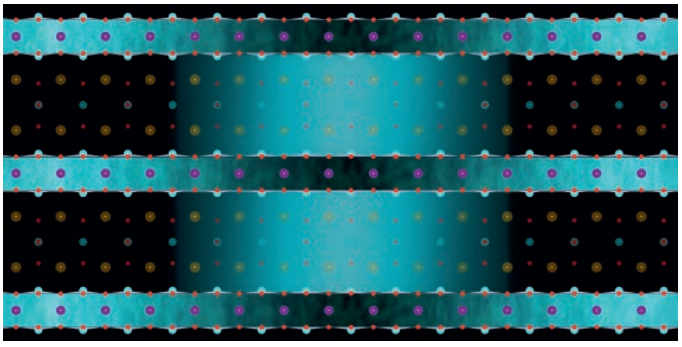
## Superconductivity at room temperature

Researchers at the Center for Free-Electron Laser Science (CFEL) have used intense flashes of infrared light to temporarily turn parts of a conventional electrical insulator into a superconductor at room temperature. Superconductors are materials that conduct electricity without any resistance. However, this usually requires the material to be cooled to about minus 270 degrees Celsius, which can only be achieved with considerable effort. Even though scientists discovered "high-temperature" superconductors around 30 years ago, these materials still need to be cooled down to at least minus 135 degrees Celsius.

At CFEL, researchers from the Max Planck Institute for the Structure and Dynamics of Matter studied a cuprate ceramic material. Cuprates are copper compounds, several of which have already proven to be high-temperature superconductors. For a material to become superconducting, the electrons in the material form "Cooper pairs". The cuprate under study with the chemical formula $YBa_2Cu_3O_{6.5}$ has a double-layered structure. The material becomes superconducting at temperatures below minus 223 degrees Celsius, because the Cooper pairs can then jump from one double layer to another without any resistance. Above this transition temperature, the Cooper pairs can only move freely within one double layer.

Using flashes of infrared light of the right wavelength, the researchers enabled the Cooper pairs to jump from one double layer to another even at room temperature. According to the research team's report in the journal *Nature Materials*, about 20 percent of the material briefly became superconducting. "Our goal is to develop a material that has the same properties, but doesn't need to be stimulated with light," explains the article's lead author, Wanzheng Hu from the team headed by Andrea Cavelleri. "It would be a real room-temperature superconductor."

Reference: Optically enhanced coherent transport in $YBa_2Cu_3O_{6.5}$ by ultrafast redistribution of interlayer coupling; Nature Materials, 2014; DOI: 10.1038/NMAT3963



A flash of infrared light enables Cooper pairs to jump from one double layer to another. Picture: Jörg Harms / MPSD

# FEMTOMENAL

## Why running can make you put on weight

Do you jog to lose a few pounds? If so, you should keep Einstein's theory of relativity in mind – at least if you're an electron in the particle accelerator of DESY's free-electron laser FLASH. According to Einstein, velocity makes matter gain mass. That's why one kilogramme of electrons ends up weighing around 2.5 tonnes after it has run through FLASH. However, at that point, the particles are also travelling at 99.999991644 percent of the speed of light. Human beings are obviously a lot slower – even Usain Bolt, the world's fastest man. During his world record run in Berlin in 2009, he only gained one tenth of a nanogramme of mass as a result of these relativistic effects. Even a single drop of sweat is a billion times heavier than that.

**1 kg**
at rest
(however, even one kilogramme amounts to a lot of electrons)

**1,059 kg**
at 30 keV or
30 percent of the speed of light
(cathode ray tube)

**2447 kg**
at 1.25 GeV or
99.999992 percent of the speed of light
(FLASH)

# Mysterious gas giants

## X-ray laser FLASH spies deep into giant gas planets

**The large gas planets of our solar system cloak themselves with impenetrable layers of cloud, successfully keeping their secrets hidden from prying eyes. We do know that the majestic gas giants Jupiter and Saturn are mostly made up of hydrogen and helium – the two lightest chemical elements. But what is really going on in the interior of such planets? The gas gets denser as the depth increases, and most of the hydrogen must actually be liquid. But whether or not the gas giants possess a solid core is as uncertain as the exact structure of their outer layers. Laboratory studies can help to improve our models of these planets.**

Four gas giants orbit our sun:
Jupiter, Saturn, Uranus and Neptune.
Our Earth, in contrast, has a solid crust
of rock, like Mercury, Venus and Mars.
Collage: NASA / JPL

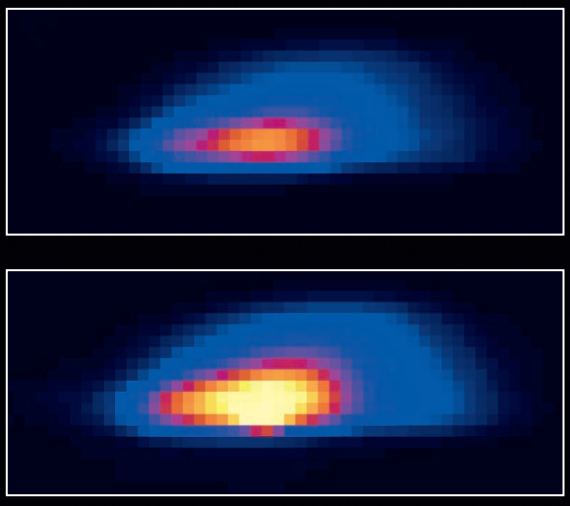
Researchers have used DESY's X-ray laser FLASH to take a sneak peek into giant gas planets. The observations of the team around Ulf Zastrau from the University of Jena reveal in a kind of super slow motion how liquid hydrogen becomes a plasma, and provide information about its thermal conductivity and internal energy exchange. These properties are of great importance for the models scientists use to form a picture of the planets' internal structure.

The atmosphere of gas planets consists mainly of hydrogen, the most abundant chemical element in the universe. "We have very little experimental knowledge about the hydrogen in the interior of such planets, despite our very good theoretical models," says Zastrau. The researchers therefore decided to use cold liquid hydrogen as a kind of sample of the planetary atmosphere. "Liquid hydrogen has a density that corresponds to that of the lower atmosphere of such large gas planets," explains Zastrau. The scientists used DESY's X-ray laser FLASH to heat the liquid hydrogen almost instantaneously from minus 253 degrees Celsius to around 12 000 degrees Celsius and to simultaneously observe the properties of the element during the heating process.

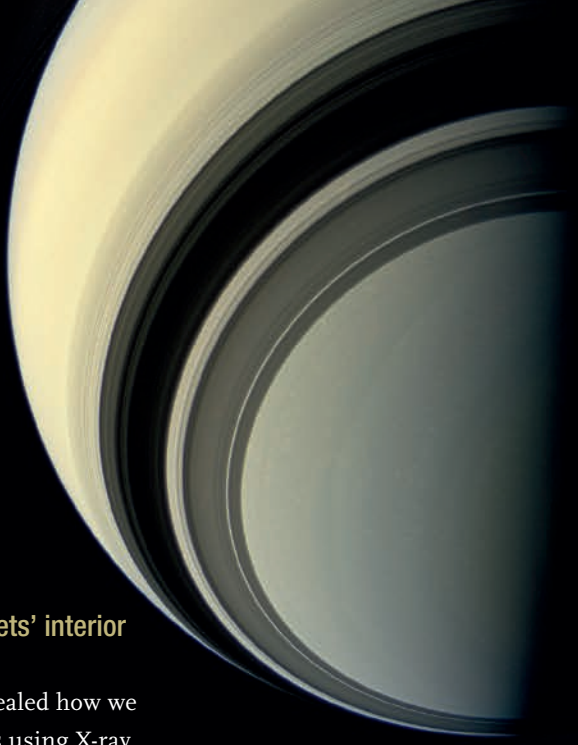
Hydrogen is the simplest atom of the periodic table, consisting of a single proton in the atomic nucleus, orbited by a single electron. Normally, hydrogen occurs as a dumbbell-shaped molecule consisting of two atoms. The X-ray laser flash initially heats only the electrons. These slowly transfer their energy to the protons, which are around 2000 times heavier, until a thermal equilibrium is reached. The molecular bonds break during this process, and a plasma of electrons and protons is formed. Although the process takes many thousands of collisions between electrons and protons, the studies showed that the thermal equilibrium is attained in just under a trillionth of a second (a picosecond).

## Recreating the cosmos in the lab

"We are carrying out astrophysics in the lab," explains Zastrau. Until now, researchers have relied on mathematical models when they wanted to describe the interior of gas planets such as Jupiter. Important parameters include the dielectric properties of hydrogen – for example, the thermal and electrical conductivities – which are crucial for correct simulation of the massive outward-directed heat flows in giant gas planets.



Scattering images of hydrogen in the liquid, unheated state (top) and two picoseconds (trillionths of a second) after being heated by a laser flash.
Pictures: Ulf Zastrau / University of Jena



The gas planet Saturn, captured by the European–American space probe "Cassini-Huygens". Picture: NASA / JPL / Space Science Institute

"The study has revealed the dielectric properties of the liquid hydrogen," reports co-author Philipp Sperling from the University of Rostock. "When you know the thermal and electrical conductivities of the individual layers of hydrogen in the atmosphere of a gas planet, you can calculate the associated temperature profile." The researchers' experiments have enabled them to locate a first point in the phase diagram of hydrogen. To create a detailed picture of the entire planetary atmosphere, the experiments will have to be repeated at other temperatures and pressures.

**We have virtually no experimental knowledge of the hydrogen in the interior of gas planets**

## Zooming in on the planets' interior

"Our experiment has revealed how we can study dense plasmas using X-ray lasers," emphasises co-author Thomas Tschentscher, scientific director at the European XFEL X-ray laser, at which first experiments are scheduled to start in 2017. "This method opens the door to further studies – for example, of denser plasmas of heavier elements and mixtures such as those existing in the interiors of planets. We hope that the results will provide us with an experiment-based answer to the question of why the planets discovered outside our solar system so far have not been found in all conceivable combinations of properties such as age, mass, size or element composition, but can all be assigned to specific groups."

In addition to the universities of Jena and Rostock as well as DESY and European XFEL, researchers from the US research centres SLAC National Accelerator Laboratory and Lawrence Livermore National Laboratory, the Helmholtz Institute Jena, the University of Oxford, the GSI Helmholtzzentrum für Schwerionenforschung, the Hamburg Centre for Ultrafast Imaging (CUI) and the University of Münster also participated in the study.

Reference: Resolving ultra-fast heating of dense cryogenic hydrogen; Physical Review Letters, 2014; DOI: 10.1103/PhysRevLett.112.105002

## Hydrogen in an exceptional state

The study required a great deal of effort, in part because hydrogen does not normally exist in liquid form on Earth. To liquefy hydrogen gas, it must first be cooled to within about 20 degrees of absolute zero – that is, to minus 253 degrees Celsius. “We use extremely pure hydrogen from a normal commercially available gas cylinder and force it through a copper block that is cooled using liquid helium,” explains DESY researcher Sven Toleikis, a member of the team.

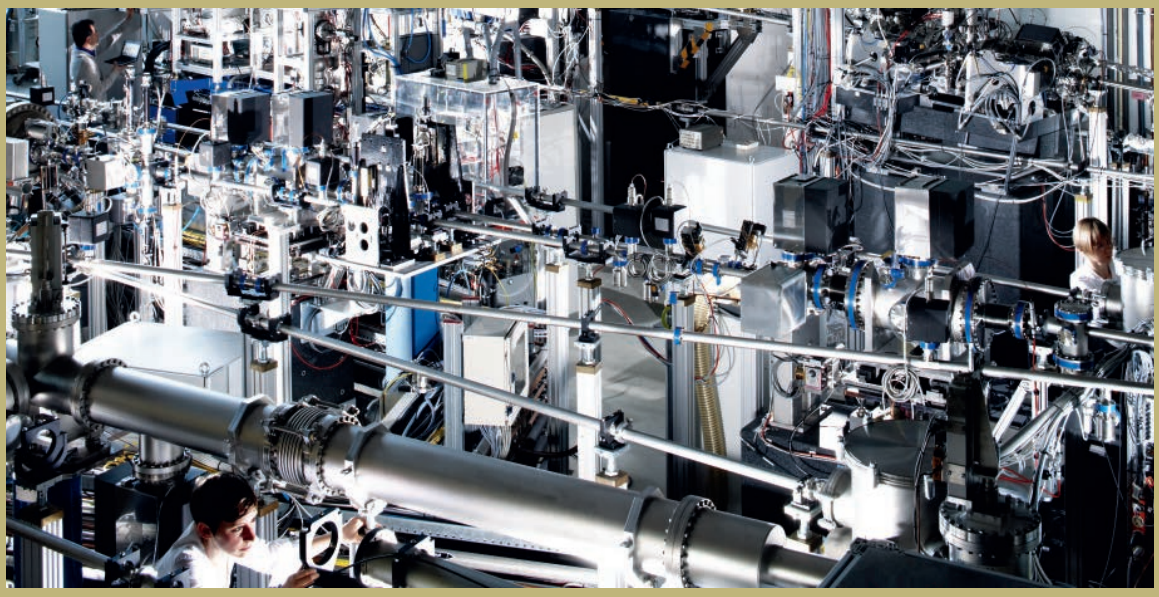
In the copper block, the hydrogen is deeply cooled and condenses. “The temperature must be controlled very precisely during this process. If the hydrogen gets too cold, it freezes and blocks the line,” says Toleikis. In such cases, a small heater is used to re-liquefy the hydrogen as needed. At the end of the copper block, a nozzle projects like a finger into the experimental vacuum chamber. From its tip flows a fine jet of liquid hydrogen, with a diameter of just one fiftieth of a millimetre (20 micrometres). This experimental setup has been constructed in the course of many years of cooperation between the University of Rostock and DESY.

To study the properties of liquid hydrogen as it vaporises, the researchers shot a beam of soft X-rays from DESY’s free-electron laser FLASH at the fine jet. “For the experiment, we used FLASH’s unique ability to split up the individual flashes,” explains Toleikis. “The first half of the flash heats up the hydrogen, and we use the second half to investigate its properties.”

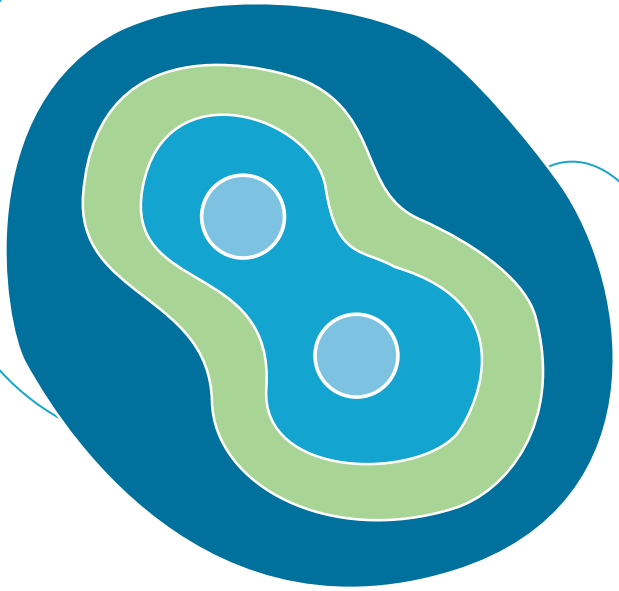
Hydrogen jet inside the experimental chamber. Picture: Sven Toleikis / DESY

Using a split-and-delay unit, which was developed in cooperation with the University of Münster and the Helmholtz-Zentrum Berlin, the second half of the flash is deliberately delayed by a tiny fraction of a second (up to 15 trillionths of a second). By studying the system in this way with slightly different delay times, the manner in which a thermal equilibrium is established between the electrons and the protons in the hydrogen can be observed in a kind of super slow motion.

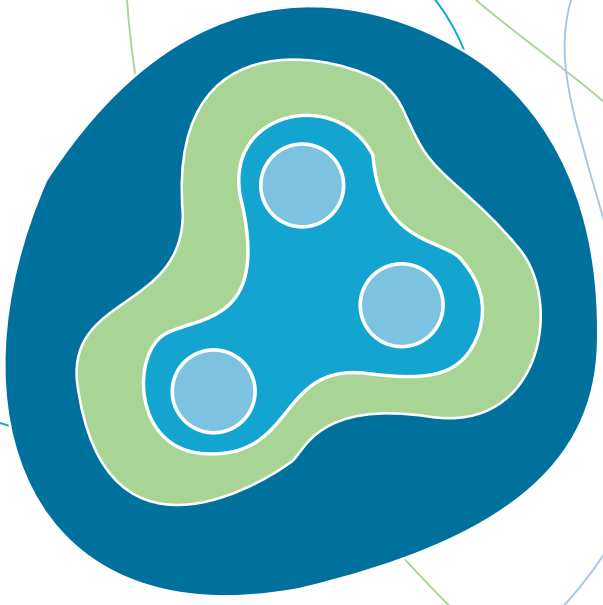
The interpretation of the observation data was not simple, however. “It took us a long time to understand what was actually happening in the experiment,” says Ronald Redmer, who leads the Rostock working group. The researchers made use of density functional theory – a standard tool of quantum physics that is used to describe systems with many electrons – to model the process. However, this standard procedure does not work for systems with two different temperatures, as in the FLASH experiment. “Before we could correctly describe the observations, we had to extend density functional theory with a two-temperature model,” reports Redmer.



FLASH experimental hall. Picture: Heiner Müller-Elsner / DESY



Particles made up of two quarks are called mesons



The protons and neutrons that make up an atom's nucleus each consist of three quarks

# Tetraquarks

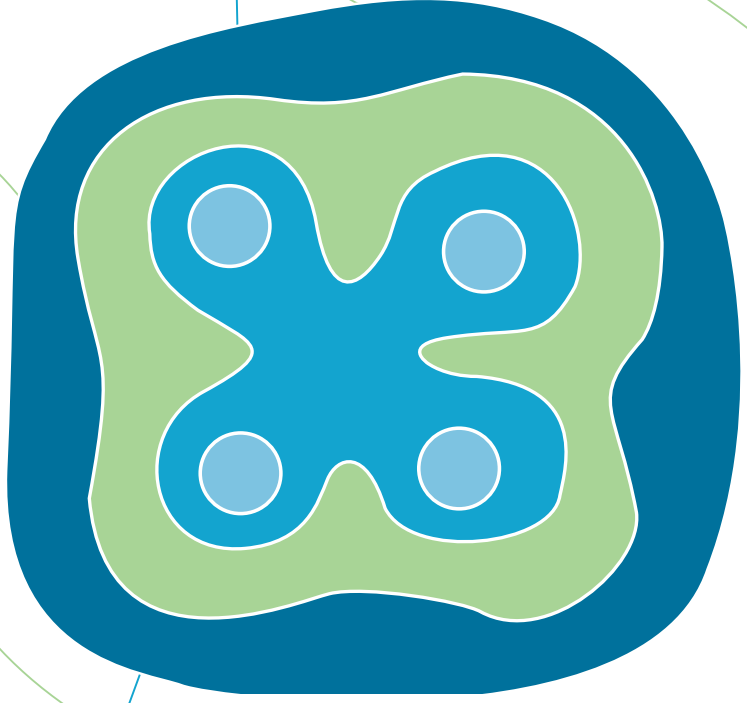
## Researchers track down particle gangs of four

**To date, particles consisting of four quarks have been theoretically conceivable, but physicists have not been able to capture any so far. However, there are now increasing indications that these exotic gangs of four really exist. Scientists from DESY are participating in the corresponding experiments.**

Atoms have nuclei composed of protons and neutrons. These, in turn, are made up of even smaller components called quarks. According to the current state of knowledge, quarks cannot be broken down any further. They are thus among the fundamental components of matter. However, these tiny entities have an unusual property – they are never found on their own; they always come in groups. For example, protons and neutrons consist of three quarks apiece. And scientists have long been familiar with mesons – particles made up of two quarks.

However, as Ahmed Ali, a theoretical physicist at DESY, points out, "In principle, the Standard Model of particle physics also permits the existence of particles consisting of four quarks. Unfortunately, the model does not tell us whether these exotic particles can exist long enough to be observable in experiments." In such experiments, physicists shoot known particles – for example, electrons – at one another. The collisions are so powerful that they can generate much heavier particles, including some that consist of quarks.

Most of these newly generated exotic particles are so short-lived that they disintegrate almost immediately. Their fragments then fly through a detector, where they are precisely measured. This enables the physicists to reconstruct which exotic particles were originally generated during the collisions. "In recent years, we have discovered more and more particles

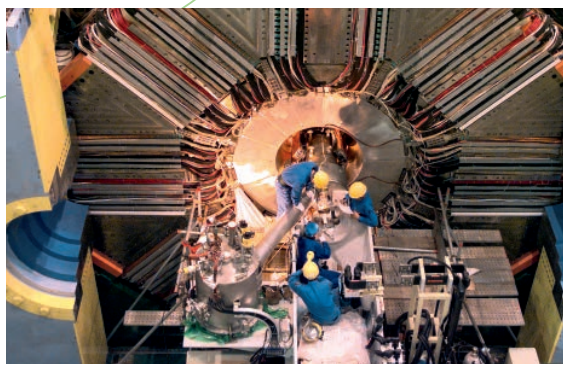


Tetraquarks, which are particles consisting of four quarks, are newcomers in the particle zoo

that obviously consist of four quarks," says DESY physicist Torben Ferber, who is participating in the Japanese Belle experiment. The Belle detector delivered data until 2010, is currently being comprehensively upgraded and will be known as Belle II in the future. Belle already detected initial indications of a four-quark particle as early as 2007, but the confirmation of these findings came only recently from the LHCb detector at the LHC super accelerator at CERN near Geneva. Another candidate was recently discovered in parallel by Belle and a Chinese experiment.

Particles that carry an electric charge seem particularly interesting. "They are something special," says Ferber. "That's because these exotic particles can't be merely excited states of known particles consisting of a quark and an antiquark." The experts think there are two possible explanations for these new particles. "They are either two mesons that are temporarily joining up to form a molecule, or four quarks that are acting together to form a tetraquark," says Ahmed Ali.

There are a number of reasons in favour of the existence of such a gang of four, but only further experiments can provide final certainty. "Belle II will begin operating in 2016, and it will deliver considerably more measurement data than its predecessor," Ferber explains. "We will then hopefully find a consistent schema behind the tetraquark candidates."

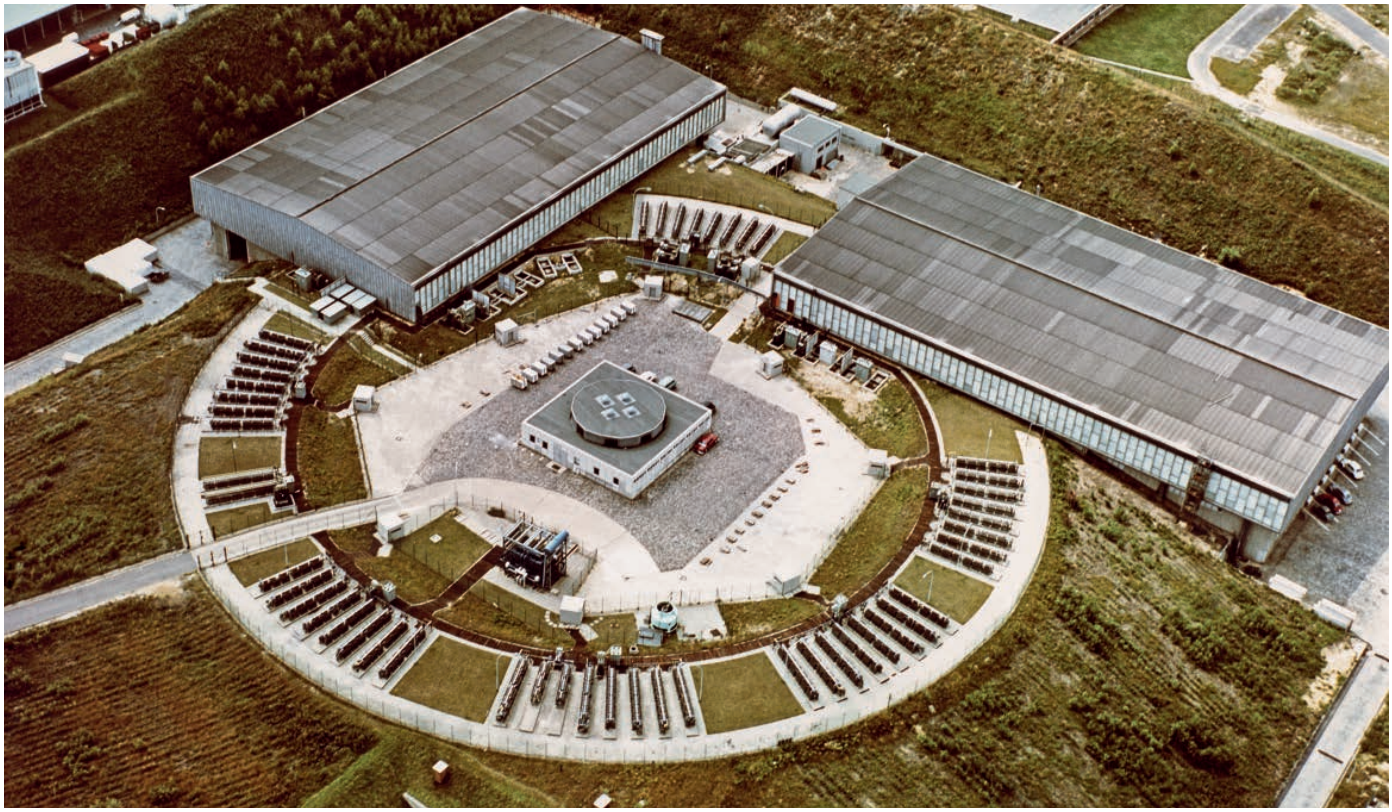


The Belle detector in Japan. Picture: KEK

The hopes go even further than that. "In principle, the Standard Model also permits the existence of particles that consist of five or six quarks," says Ahmed Ali. "We call them pentaquarks and hexaquarks, respectively." As long as a decade ago, several research groups had registered possible indications of a pentaquark. However, further experiments were not able to confirm these clues. Nonetheless, in the future, the physicists will continue to look out for these gangs of five and six quarks as well when they analyse their measurement data.

References: Observation of a Charged Charmoniumlike Structure in $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s}=4.26$ GeV; Physical Review Letters, 2013; DOI: 10.1103/PhysRev-Lett.110.252001

Study of $e^+e^- \to \pi^+\pi^- J/\psi$ and Observation of a Charged Charmoniumlike State at Belle; Physical Review Letters, 2013; DOI: 10.1103/PhysRev-Lett.110.252002



Electrons first flew through the German Electron Synchrotron "DESY" 50 years ago, when the facility was originally put into operation. Picture: DESY

# Pioneering detectors

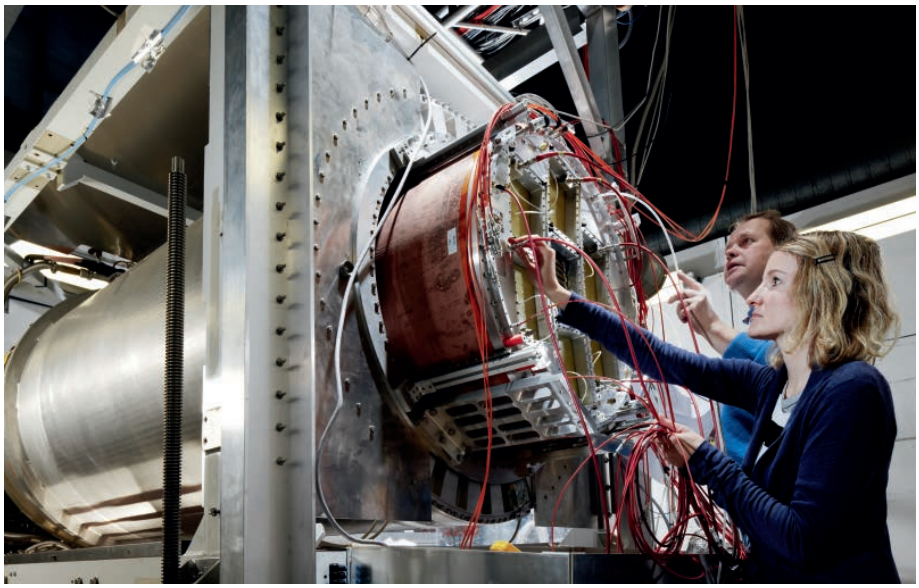
## DESY's oldest accelerator has considerable future potential

After passing through the security gate, DESY physicist Marcel Stanitzki enters a ring tunnel that has concrete walls several metres thick. Stanitzki walks towards an inconspicuous monitoring glass that protrudes from a stainless steel pipe. "If you take a close look, you can see a small fork inside," he says. "We clamp hair-thin carbon fibres in this fork."

The fragile structure is the starting point for a rather unfamiliar research facility at DESY – the test beam. It is indispensable for many experts, who use it to test new detector components, most of which are employed in the field of particle physics. The test beam is generated at DESY's oldest accelerator – the German Electron Synchrotron, whose German acronym ("DESY") gave the lab its name. Half a century ago, on 25 February 1964, physicists sent electrons through the 300-metre-long ring of stainless steel pipe for the first time, accelerating the particles to nearly the speed of light. Although the synchrotron's experimental programme ended in 1978, the facility continued to run, serving as a pre-accelerator. Since then, it has been reconstructed and modernised several times. "It's still an extremely good and reliable machine," says DESY physicist Ingrid-Maria Gregor. "That's a big advantage for our test beam."

The researchers use the beam to test new components for particle detectors. As parts of accelerator experiments, these detectors register the collisions of fast particles. Physicists subsequently analyse these collisions to find out whether they generated new exotic elementary particles such as the famous Higgs boson. The detectors' task is truly daunting, because the collisions create dozens of new particles, whose tracks have to be measured as accurately as possible.

To thoroughly test new prototype detectors, experts from all over the world bring them to Hamburg. "At our test facility, we bombard these prototypes with electrons or positrons," explains Gregor. "In this way, we can find out whether a detector works as expected." Because the electrons in the test beam have precisely defined properties, the experts know exactly how their detector should respond to the particles.



Using the DESY test beam to measure a prototype tracking chamber. The magnet was imported from Japan, the field cage was made in Germany and the various read-out modules come from all over the world.
Picture: Heiner Müller-Elsner / DESY

The test beam is cleverly produced, starting with the hair-thin carbon fibres visible through the accelerator's monitoring glass. "When the synchrotron's fast electron beam hits these fibres, it creates high-energy particles of light known as photons," explains Marcel Stanitzki, the test facility's coordinator. "These photons then hit small metal plates." The plates convert the photons into electrons and positrons, which zip into a large green magnet. This magnet serves as a kind of filter that only allows particles of a certain energy to get through. But why make such a detour instead of simply using the electrons that are accelerated by the synchrotron? "Using the original electrons would interfere too much with pre-accelerator operation," replies Stanitzki. "Moreover, our approach lets us set the energy and particle rate of the electrons to any values we like and tailor them to the tests." After the particles are generated, they fly through pipes in the metre-thick tunnel wall until they reach one of three measuring stations in the DESY experimental hall. Physicists have developed a unique array of measurement equipment that they have set up at the stations. These measurement devices include pixel telescopes, which "allow us to tell to within a few micrometres where a particle passed through a detector," says Gregor. "That's something we need to know in order to precisely reconstruct a particle's path." The experts at DESY have built six pixel telescopes to date, half of them for other research institutes such as CERN in Geneva.

Another special feature is the facility's large, barrel-shaped solenoid magnet. "Most particle detectors contain such magnets nowadays," says Stanitzki. "They are used to bend the particles' path so that their momentum can be determined." Detector components located in such magnets can be tested in the solenoid under realistic conditions. "It's a unique facility," says Stanitzki. "This is the only place that has one."

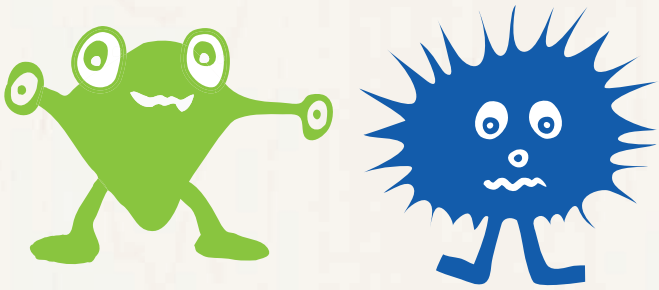
The demand for the test facility is correspondingly large. In 2013 alone, around 400 experts came to Hamburg to try out new detector components in shifts around the clock. Many of the new detectors were designed for the world's largest accelerator, the LHC in Geneva. Other experts use the facility to test prototypes for the planned International Linear Collider (ILC) and various other facilities in Darmstadt (Germany), Japan, the USA and elsewhere. Detectors that might one day be used for medical applications have also been tested at DESY, as have components for the international fusion experiment ITER. "There's a huge demand," says Gregor. "We will need the test facility for at least another 20 years." This means that the DESY veteran will continue to play an important role in Hamburg's accelerator line-up.

## Accelerator upcycling

Upcycling is actually the name of a new trend ensuring that high-quality designer products made of recycled materials find their way into our homes and wardrobes. DESY used this principle long before the word for it was coined in the 1990s. At DESY, particle accelerators that were no longer useful for particle physics were given a new lease of life as pre-accelerators for newer, bigger particle racetracks or were upgraded with the latest high-tech so that they could generate light and be reincarnated as brilliant X-ray sources. The long-term effectiveness of accelerator upcycling is demonstrated by the fact that even DESY's longest-serving accelerator is again attracting users from all over the world to Hamburg.

# Which particle best suits you?

**In the Particle Zoo, elementary particles become real personalities**



**Are you an optimist, someone who loves the company of others and is easily distracted? Then your match in the world of elementary particles is perhaps an up quark. Or are you rather a volatile person, tending toward a pessimistic worldview? Then a muon could be more your type. In contrast, WIMPS, particles for which a frantic search is under way, are recommended for dreamers...**

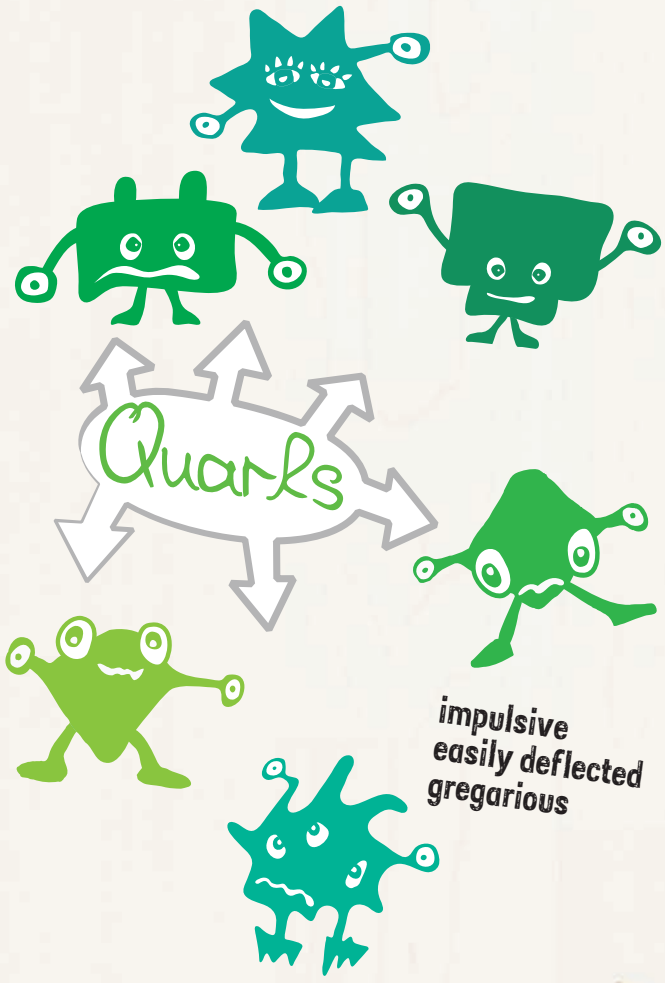

Are you getting curious? This is precisely what DESY aims to achieve with its Particle Zoo. In partnership with the Universum Science Center in Bremen, Germany, DESY vividly presents particle physics knowledge in an exhibition that puts faces on the building blocks of our world. In the Particle Zoo, the elementary particles are depicted as small colourful monsters that also possess true personalities. You can explore them online at: **http://teilchenzoo.desy.de/particlomatic.**

This particle personality test invites visitors to an encounter of a different kind, where they can get to know the otherwise abstract particles better and learn more about their favourite individual particles. "Exciting knowledge is hidden behind the complicated formulas of particle physics – knowledge that we also want to convey to those who aren't particularly interested in physics," explains DESY director Helmut Dosch. "By bringing the particles to life, we aim to provide vivid access to our research in a way that will appeal to young people and get them excited about physics."

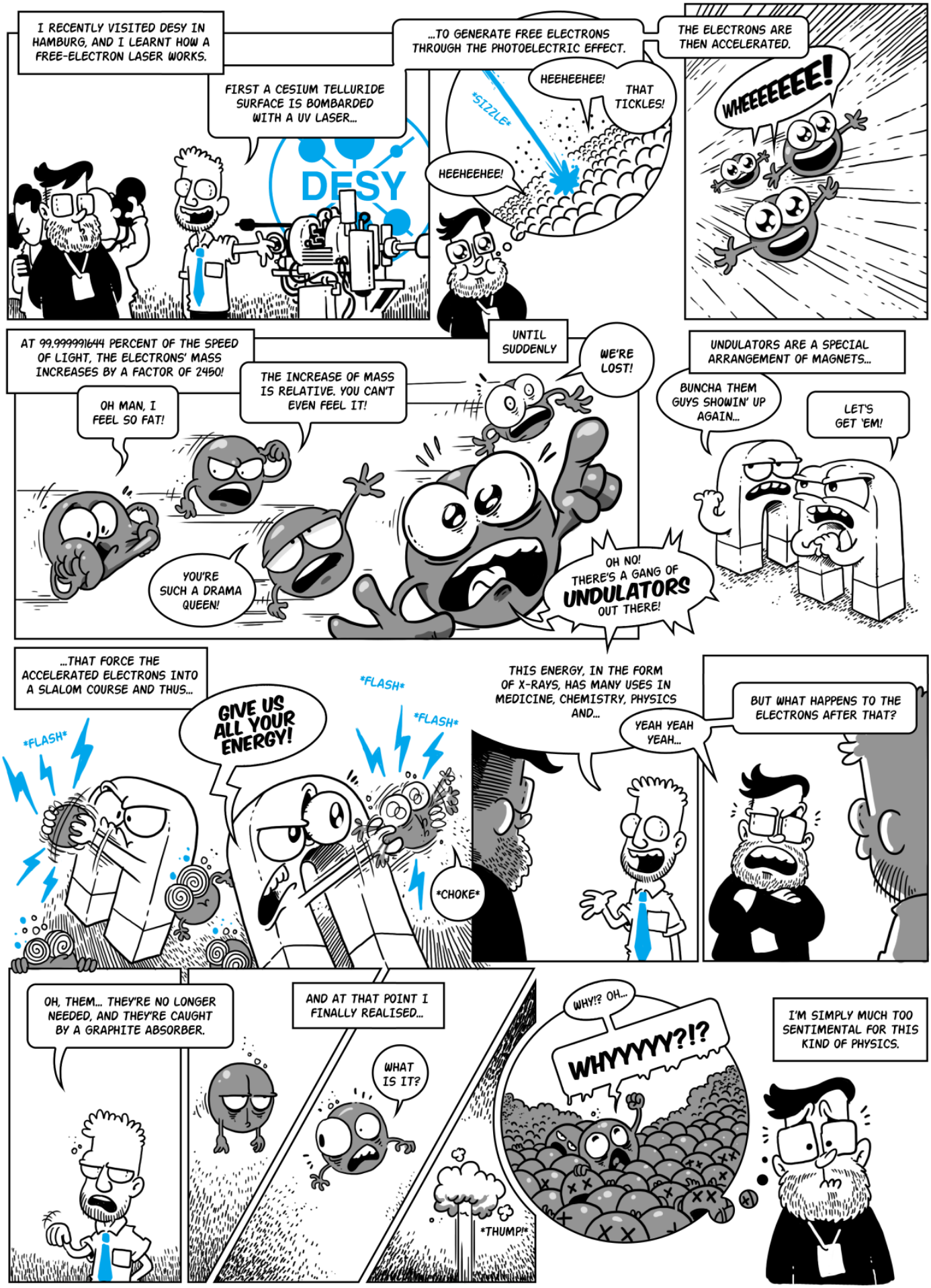
The playful approach of the personality test casually conveys hidden facts about physics. For example, visitors who are revealed to be up quarks are not only matched up with a friendly green particle monster, but also presented with the following background information:

"The up quark is one of the six different kinds of quarks. It is a lightweight quark. Up quarks have a positive electric charge. (We could therefore call them optimistic.) What all six quark types have in common is that they never occur alone: quarks are gregarious. They always bond together in groups of two or three to form other kinds of particles. The up quark was among the first three quark types detected in experiments carried out in 1969. The word 'quark' can be traced back to a passage in a novel by James Joyce." People who want to find out more can read a brief biography of each elementary particle, which is packed with interesting and valuable information presented in terms that can be easily understood. Among other things, you can find out why the elementary particles, despite their unimaginably small size, exert so much influence on our daily lives. The traces left by quarks and their cohorts also lead to meaningful questions about humanity: What happened during the Big Bang? How did matter, space and time originate? And what ultimately holds the universe together?

Seven short films (in German), in which television host Delf Deicke grills various DESY physicists, accompany this entertaining introduction to the realm of the smallest particles. The world of particle physics is conveniently provided for your home viewing pleasure at: **http://teilchenzoo.desy.de/videos.**




The Particle Zoo can be visited as a virtual exhibition at: http://teilchenzoo.desy.de/exhibition


I RECENTLY VISITED DESY IN HAMBURG, AND I LEARNT HOW A FREE-ELECTRON LASER WORKS.
FIRST A CESIUM TELLURIDE SURFACE IS BOMBARDED WITH A UV LASER...
DESY
...TO GENERATE FREE ELECTRONS THROUGH THE PHOTOELECTRIC EFFECT.
*SIZZLE*
HEEHEEHEE!
THAT TICKLES!
HEEHEEHEE!
THE ELECTRONS ARE THEN ACCELERATED.
WHEEEEEEE!
AT 99.999991644 PERCENT OF THE SPEED OF LIGHT, THE ELECTRONS' MASS INCREASES BY A FACTOR OF 2450!
OH MAN, I FEEL SO FAT!
THE INCREASE OF MASS IS RELATIVE. YOU CAN'T EVEN FEEL IT!
YOU'RE SUCH A DRAMA QUEEN!
UNTIL SUDDENLY
WE'RE LOST!
OH NO! THERE'S A GANG OF UNDULATORS OUT THERE!
UNDULATORS ARE A SPECIAL ARRANGEMENT OF MAGNETS...
BUNCHA THEM GUYS SHOWIN' UP AGAIN...
LET'S GET 'EM!
...THAT FORCE THE ACCELERATED ELECTRONS INTO A SLALOM COURSE AND THUS...
*FLASH*
GIVE US ALL YOUR ENERGY!
*FLASH*
*FLASH*
*CHOKE*
THIS ENERGY, IN THE FORM OF X-RAYS, HAS MANY USES IN MEDICINE, CHEMISTRY, PHYSICS AND...
YEAH YEAH YEAH...
BUT WHAT HAPPENS TO THE ELECTRONS AFTER THAT?
OH, THEM... THEY'RE NO LONGER NEEDED, AND THEY'RE CAUGHT BY A GRAPHITE ABSORBER.
AND AT THAT POINT I FINALLY REALISED...
WHAT IS IT?
*THUMP!*
WHY!? OH...
WHYYYYY?!?
I'M SIMPLY MUCH TOO SENTIMENTAL FOR THIS KIND OF PHYSICS.

# Imprint

femto is published by
Deutsches Elektronen-Synchrotron DESY,
a research centre of the Helmholtz Association

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ISSN 2199-5192

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**Copy deadline**
June 2014

**Cover picture** Computer graphic of a flu virus: Its shell contains special proteins that recognise a host cell and can dock onto it. Virus proteins are promising target points for the active ingredients of medications that can combat infections at an early stage. With the help of structural biology, the structure of such proteins can be deciphered on the atomic scale, providing the foundation on which customised medicines can be developed. Picture: Roger Harris / Science Photo Library

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DESY

## The DESY research centre

DESY is one of the world's leading particle accelerator centres. Researchers use the large-scale facilities at DESY to explore the microcosm in all its variety – ranging from the interaction of tiny elementary particles to the behaviour of innovative nanomaterials and the vital processes that take place between biomolecules. The accelerators and detectors that DESY develops and builds at its locations in Hamburg and Zeuthen are unique research tools. The DESY facilities generate the most intense X-ray radiation in the world, accelerate particles to record energies and open up completely new windows onto the universe.

DESY is a member of the Helmholtz Association, Germany's largest scientific organisation.

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