femto

The DESY research magazine – Issue 02|14

Surfing the plasma wave
The new accelerator technology is small, compact and powerful

Extremely flexible
New solar cells are produced on rolls

Bacteria slayers
How viruses attack the cell walls of bacteria

SPOTLIGHT

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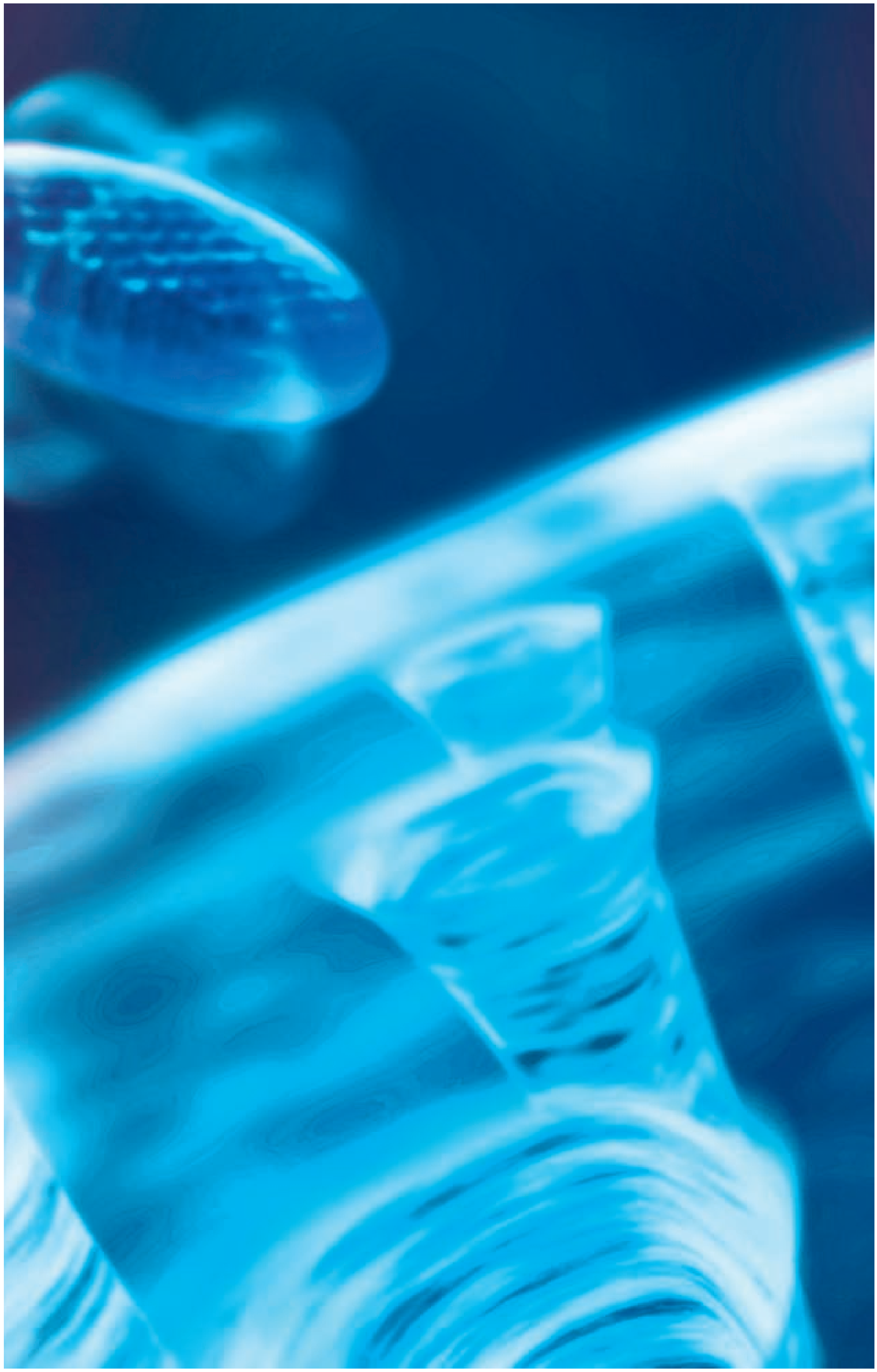
The world's biggest particle accelerator, the LHC, is looking for SUSY particles, the building blocks of a new understanding of the universe

DESY

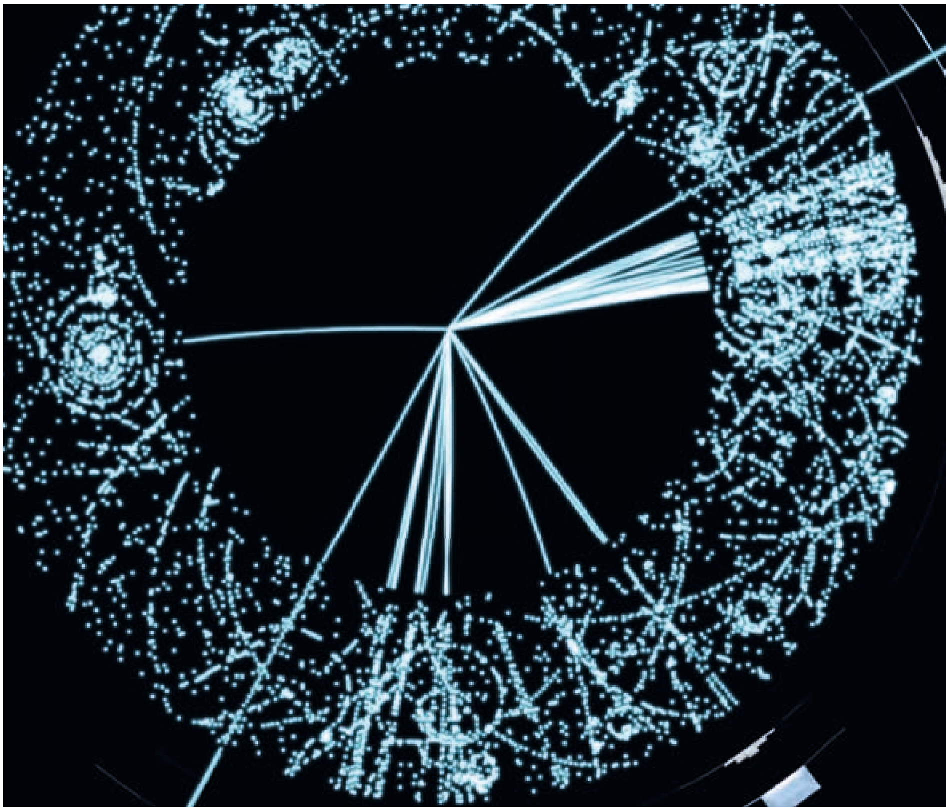


Quantum vortices in nanodroplets

A whirlpool that rotates in a drop of water instead of a bathtub drain? It certainly would be an unusual phenomenon. Even more exotic are the tiny quantum vortices that arise in cold droplets of liquid helium. An international research team including DESY scientists has for the first time observed and characterised such vortices in nanodroplets only 0.2 to 2 thousandths of a millimetre in diameter.

Picture: SLAC National Accelerator Laboratory

The noble gas helium becomes liquid at minus 269 degrees Celsius. Below minus 271 degrees, a quantum effect occurs, which causes the liquid helium to lose all internal friction and become superfluid. In this exotic state, it can even crawl up walls. To explore the dynamics of superfluid helium, the scientists illuminated tiny helium nanodroplets with the X-ray laser LCLS at the SLAC National Accelerator Laboratory in the USA. To this end, they sprayed liquid helium through a fine nozzle into a vacuum chamber. Because the droplets expanded inside the nozzle, they began to rotate up to 14 million times a second – far faster than a normal round drop could withstand, according to the laws of classical physics. Due to the rapid rotation, many tiny quantum vortices formed within the nanodroplets. The scientists are now trying to understand the origin of this quantum rotation and ultimately to control it.



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The search for supersymmetry

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The search for supersymmetry

This theory is really something: SUSY, or supersymmetry, would solve a whole series of riddles in the universe in one fell swoop – if SUSY in fact exists. The world's biggest particle accelerator, the LHC, is looking for SUSY particles, the building blocks of a new understanding of the universe.

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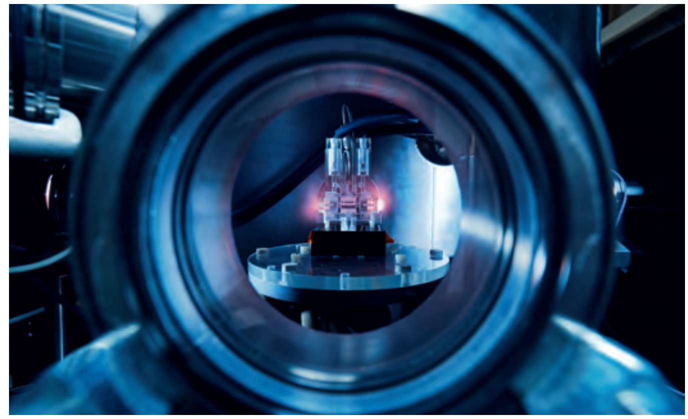

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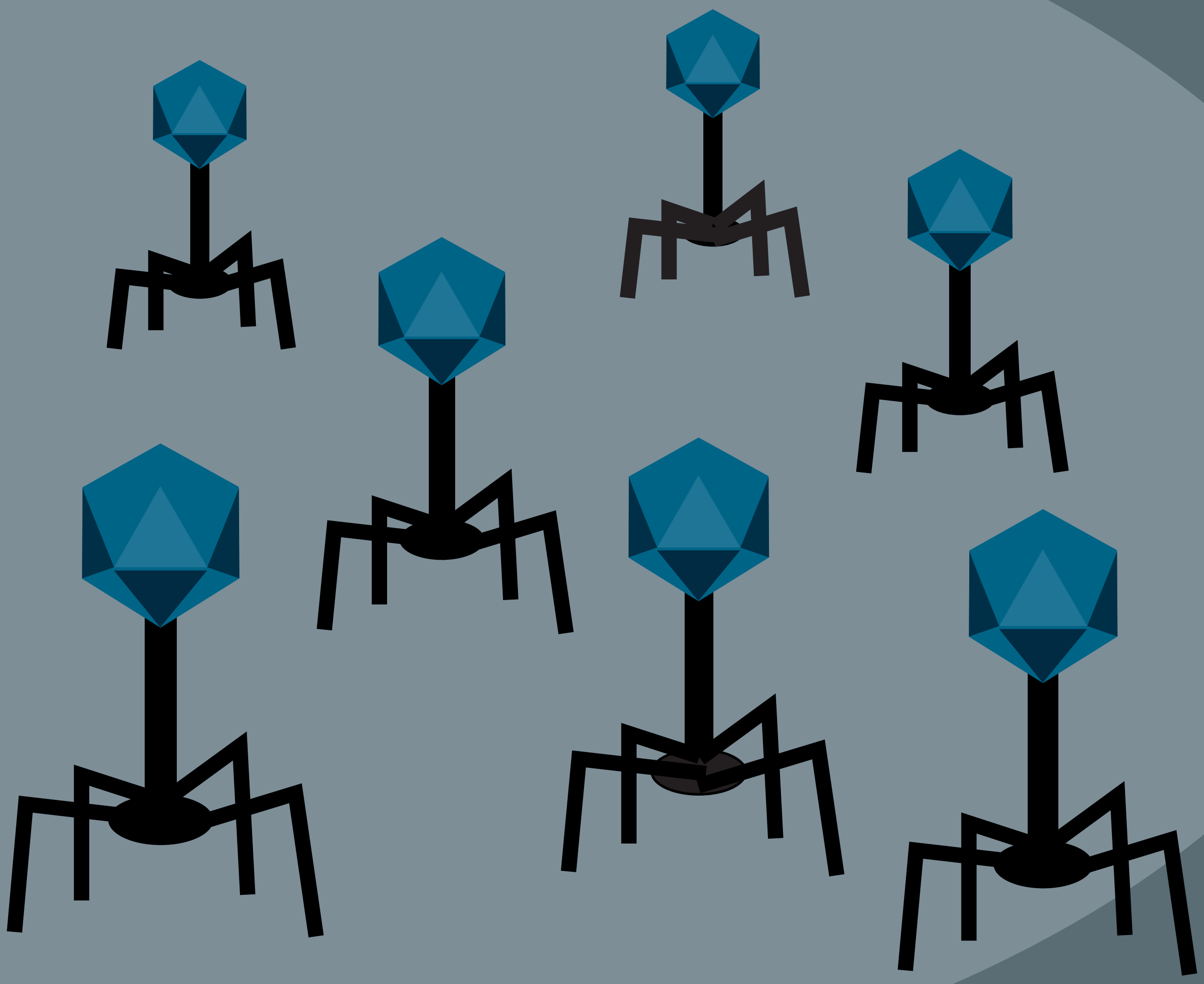


Viruses that kill bacteria

X-ray imaging shows how bacteriophages attack the cell walls of bacteria

There are viruses that do not make us ill, but instead attack the bacteria that make us ill. These viruses are called bacteriophages, the Greek word for “bacteria devourers”. Their name says it all, because these viruses only infect bacteria. Each phage specialises in certain species of bacteria. Discovered 100 years ago, these viruses are found in nearly every place where bacteria are common. The tiny, robot-like virus particles inject their genomes into bacterial cells in order to reprogram them to produce proteins for new phages. The cell eventually dissolves, releasing large numbers of phages that go on to infect other bacteria.

Some viruses that target bacterial cells look like miniature robots. Their genetic information is contained in the angular head.

In the light of increasing antibiotic resistance, bacteriophages and their enzymes could offer a promising alternative

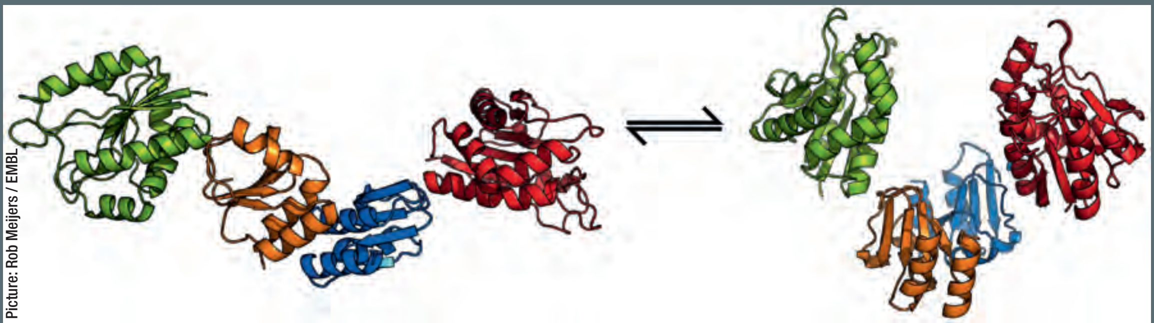
The targeted manner in which phages operate allows them to be very efficiently used against pathogenic bacteria. Unfortunately, their use is still complicated, because the infecting bacteria first have to be analysed, and the appropriate phages then have to be found, processed and applied over a relatively long period of time. Antibiotics achieve quicker and easier results, unless the bacteria are resistant to them. Multiresistant microbes that almost no medication can affect are the bane of hospitals. Because intensive animal farming uses a lot of antibiotics, it creates especially many resistant bacteria that also pose a major threat to human beings. That's reason enough to once again devote more attention to bacteria devourers in order to find alternatives to antibiotics in the fight against infections.

Researchers from the European Molecular Biology Laboratory (EMBL) used DESY's X-ray source PETRA III to find out how bacteriophages kill the life-threatening diarrhoea pathogen *Clostridium difficile*. The scientists were able to show that the viruses release certain enzymes in order to dissolve the bacteria's cell walls. Such crucial information helps scientists develop new therapies using bacteriophages. "In the light of increasinng antibiotic resistance, bacteriophages and their enzymes could offer a promising alternative," says Rob Meijers, who heads the EMBL group. "The results could allow us to engineer effective, specific bacteriophages, not just for *Clostridium difficile* infections but also for a wide range of bacteria related to health, agriculture and the food industry."

Electron microscopy image of a *Clostridium difficile* bacterium

Because the bacterium *Clostridium difficile* is resistant to an increasing number of antibiotics, it is becoming a serious problem in many hospitals and other healthcare institutes, where it can cause life-threatening cases of diarrhoea. Patients who receive broad-spectrum antibiotic treatment for other reasons are particularly at risk. *Clostridium difficile* naturally occurs in human gut flora and poses no problem in healthy individuals, but in patients treated with antibiotics a large amount of normal gut flora is wiped out. Under some circumstances, this allows the more resistant and persistent *Clostridium difficile* to increase uncontrollably in number, leading to complications such as severe diarrhoea. According to the Berlin-based Robert Koch Institute, the number of such severe cases tripled in Germany between 2008 and 2013.

Such cases are often difficult to treat, precisely because the diarrhoea bacteria are now unresponsive to many antibiotics. A potential alternative treatment would be to use bacteriophages. However, phages are still hard to control and bacteria can quickly become resistant to them as well. In order to develop effective bacteriophage therapies, a clearer understanding of the viruses'



The endolysins under investigation are activated by switching from a tensed, stretched state (left) to a relaxed state (right).

The switch from one state to the other releases the enzyme, which then begins to degrade the bacterial cell wall

life cycle is needed – in particular, how the viruses destroy the bacterial cell wall. While it is known that the bacteriophages produce enzymes called endolysins to do this, just how these enzymes are activated remains a crucial missing part of the puzzle.

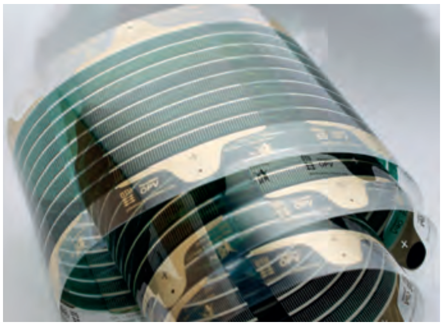
Attacking bacteria's cell walls

With the help of the intense X-rays generated by DESY's PETRA III research light source, scientists have now discovered one of the activation mechanisms of endolysins that attack bacteria of the genus *Clostridium*. "These enzymes appear to switch from a tensed, elongated shape, where a pair of endolysins are joined together, to a relaxed state where the two endolysins lie side by side," explains EMBL researcher Matthew Dunne. "The switch from one state to the other releases the enzyme, which then begins to degrade the bacterial cell wall." Once the cell wall begins to break down, the bacterial cell can no longer withstand its own internal pressure and explodes, releasing new bacteriophages that go on to infect other bacterial cells.

In collaboration with Melinda Mayer and Arjan Narbad from the Institute of Food Research in Norwich, UK, the scientists compared two different endolysins. One was retrieved from bacteriophages that attack *Clostridium difficile*, while the other digests the cell wall of a *Clostridium* species that causes problems in cheese production. At the EMBL measuring station on the DESY campus in Hamburg, researchers used X-ray crystallography and other structural biology techniques to deduce the enzymes' three-dimensional structure. From that structure, they were able to infer how the endolysins work.

"Remarkably, we found that the two endolysins have a common activation mechanism," explains Dunne. From this, the researchers conclude that the transition from a tensed state to a relaxed state is probably a common tactic. This knowledge could allow scientists to turn additional viruses into allies in the fight against other antibiotic-resistant bacteria.

PLoS Pathogens, 2014; DOI: 10.1371/journal.ppat.1004228



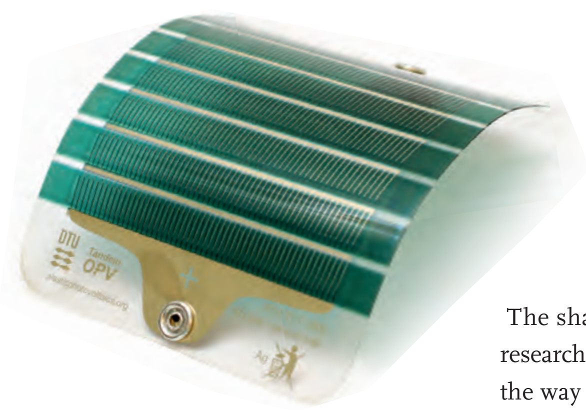
Pictures: Markus Hösel / DTU

Plastic tandem solar cells could be used in many ways.

Flexible, versatile, innovative – the new generation of solar cells

Tandem solar cells under the X-ray microscope

Flexibly shapeable, light and inexpensive solar modules could become a versatile, creative component of building façades, car roofs and windows – thanks to a new generation of solar cells that offers applications far beyond the conventional systems on roofs or in fields. The new solar cells are made of plastic and rely on organic semiconductors. Moreover, they can be produced using printing processes that conserve material and energy, thus making inexpensive manufacturing possible. However, various challenges still need to be overcome before the organic solar cells will be ready for the market. The energy conversion efficiency needs to be improved, the production costs lowered and the life of the materials and modules increased.



The sharp X-ray vision of DESY's research light source PETRA III is paving the way for a new method of producing cheap, flexible and versatile solar cells. The method developed by Danish scientists makes it possible to produce plastic tandem solar cells many metres long. The scientists used a production process in which the different layers of a polymer solar cell are coated from various solutions onto a flexible foil substrate. Using this method, plastic solar cells can be produced rapidly and cheaply in almost any desired length.

The production process is known as roll-to-roll, because the uncoated substrate is taken from one roll and rolled up on another after it has been coated. The technique has already been used to manufacture single solar cells several kilometres long.

However, the energy yield of this type of solar cell is not very high. To increase the efficiency, a team from the Technical University of Denmark (DTU) in Roskilde came up with a method for stacking a second polymer solar cell on top of the first. Because each of the cells absorbs a different part of the solar spectrum, the resulting tandem solar cell converts more of the incoming sunlight into electricity, leading to an increase in the energy yield.

But multilayer coating presents several new challenges, as senior researcher Jens W. Andreasen explains: “Lab studies have shown that already coated layers may be dissolved by the solvent used for the following layer, causing complete failure of the solar cell.”

Jens Wenzel Andreasen experimenting with polymer solar cells

To prevent this dissolution of the first solar cell, the scientists added a protective coating between the two solar cells of their tandem coating structure. The protective coating contains a zinc oxide layer that is just 40 nanometres (millionths of a millimetre) thick – about a thousand times thinner than a human hair.

The solar cell structure is very delicate, consisting of 12 individual layers altogether. Imaging the complete structure is challenging

The scientists used the sharp X-ray vision of PETRA III to check the shape and integrity of the protective coating and the other layers of the tandem solar cell. “The solar cell structure is very delicate, consisting of 12 individual layers altogether. Imaging the complete structure is challenging,” reports DESY researcher Juliane Reinhardt, who was involved in the measurements. “And the sample was just two by four micrometres in size.” One micrometre is one thousandth of a millimetre.

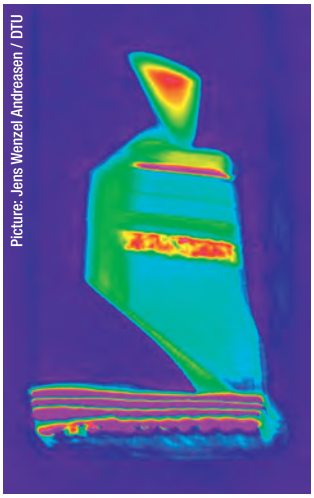
Still, with the brilliant X-ray beam the researchers could peer into the delicate layer structure in fine detail, using a technique called 3D ptychography. This method reconstructs the shape and chemistry of a sample from the way it diffracts the incoming X-rays. However, for a full 3D reconstruction, the sample has to be scanned from all sides and numerous angles. The advantage of ptychography is that the combination of the overlapping diffraction images yields a higher resolution than would be physically possible with conventional X-ray imaging alone. And in contrast to high-resolution electron microscopy, X-ray ptychography can also look deep inside the sample.

“With 3D ptychography, we were able to image the complete roll-to-roll coated tandem solar cell, showing, among other things, the integrity of the 40-nanometre-thick zinc oxide layer in the protective coating, which successfully preserved underlying layers from solution damage,” explains DESY scientist Gerald Falkenberg. “These are the 3D ptychography measurements with the highest spatial resolution we have achieved so far. The results show that with the correct formulation of the intermediate layer, the underlying solar cell is protected from dissolution.”

This result paves the way to a possible industrial application of the technique. “A complex multilayer device like a polymer tandem solar cell may fail in multiple ways,” Andreasen points out. “What we were able to see with 3D ptychography was that the preparation of the substrate electrode combines the good conductivity of a coarsely structured silver electrode with the good film-forming ability of a conducting polymer, which infiltrates the silver electrode and forms a smooth surface for the subsequent layers.” This is what allows the coating of very thin layers at very high speeds, while still forming contiguous layers without pinholes.

We were now able to verify that we can coat contiguous, homogenous layers, roll-to-roll from solution

Looking into the complete structure can also provide information for a possible optimisation of the solar cell or the production process. “In principle, we make the devices without knowing what the internal structure looks like in detail. But knowing the internal structure tells us which parameters we can modify and which factors are important for the device architecture, for example the special type of substrate electrode and the formulation of the intermediate layer,” Andreasen explains. “We were now able to verify that we can coat contiguous, homogeneous layers roll-to-roll from solution, at speeds of up to several metres per minute. We have shown that roll-to-roll processing of tandem solar cells is possible,



Picture: Jens Wenzel Andreasen / DTU

Ptychographic phase contrast projection of the polymer tandem solar cell stack (two by four micrometres in size), showing the silver electrode (wide red-yellow band) with a conducting polymer layer on top. The two solar cells above (light blue) are separated by a thin zinc oxide layer (green). The second electrode (red) is visible above the second solar cell. The triangle on top is the cut-off of a tungsten pin used to manipulate the sample under a scanning electron microscope.

with all of the layers roll-coated from solution, and that it is only possible if we use a specific formulation of the intermediate layer between the two solar cells of the tandem structure."

The polymer tandem solar cell produced in the test converts 2.7 percent of the incoming sunlight into electricity, which is far below the efficiency of conventional solar cells. "The efficiency is low, compared to conventional solar cells, by a factor of 7 or 8, but one should consider that the production cost of this type of solar cell is several orders of magnitude lower than that of conventional solar cells. This is the particular advantage of polymer solar cells," explains Andreasen. "Furthermore, this is the first example of a roll-to-roll coated tandem solar cell where the efficiency of the tandem device actually exceeds that of the two individual sub-cells."

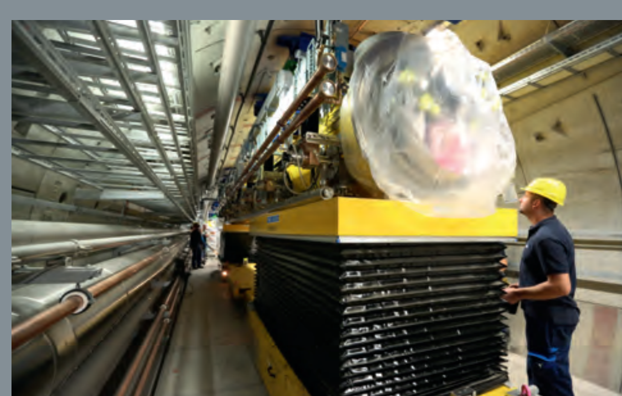
Advanced Energy Materials, 2014; DOI: 10.1002/aenm.201400736

FEMTOPOLIS

A mole for modules

Staff at DESY affectionately call the device "Mullewupp", after the Low German word for "mole". It is used for all transport tasks in the underground tunnel system of the European XFEL X-ray laser. The main items it has to transport are the 101 modules that are currently being assembled to form the X-ray laser's 1500-metre-long accelerator. Each module is 12 metres long and weighs 8 tonnes. Not only do the modules have to be moved down the tunnel, they also have to be raised to the tunnel ceiling, where they are attached. To do that, the Mullewupp is a lifting platform as well as a transport device, and it can also be equipped with an additional crane. The device has four drive motors and an all-wheel-drive steering system. It can reach a top speed of two to four kilometres per hour. It doesn't need to be fast, only strong. The approximately 19-metre-long module transport vehicle, whose massive battery is conveyed in a separate waggon, can carry a load of 12 tonnes, which it can lift almost 2.5 metres above the floor. The Mullewupp can also transport containers. Moreover, the signal-yellow vehicle is a real head-turner and a big attraction on open days. The accelerator experts at DESY are therefore justifiably proud of their "mole", which has always done its job reliably in the tunnel system.

Pictures: DESY



Picture: CERN

Computer simulation of a SUSY event in the ATLAS detector at the LHC

SPOTLIGHT

SHOW YOURSELF!

The world's biggest particle accelerator, the LHC, is looking for SUSY particles – the building blocks of a new understanding of the universe

The theory of supersymmetry, or SUSY for short, staggers the imagination. It is well worth the effort, however, because despite the huge amount of knowledge that particle physicists have already gained about our world, their so-called Standard Model describes only five percent of the universe. Supersymmetry promises to extend this very successful but limited worldview by putting hypothetical superpartners next to the particles that have already been discovered. SUSY, the "great doubler", would instantly solve a whole series of riddles in the field of particle physics. That's why the world's largest particle accelerator, the Large Hadron Collider (LHC) in Geneva, is now being equipped to search for the new particles. After discovering the Higgs particle in 2012 – and thus prompting the award of the Nobel Prize to the theoreticians who first postulated the particle – the LHC "discovery machine" will now employ far higher energies to track down the avidly sought-after SUSY particles.

Too beautiful to be wrong

Why supersymmetry, or SUSY, is so appealing to particle theorists

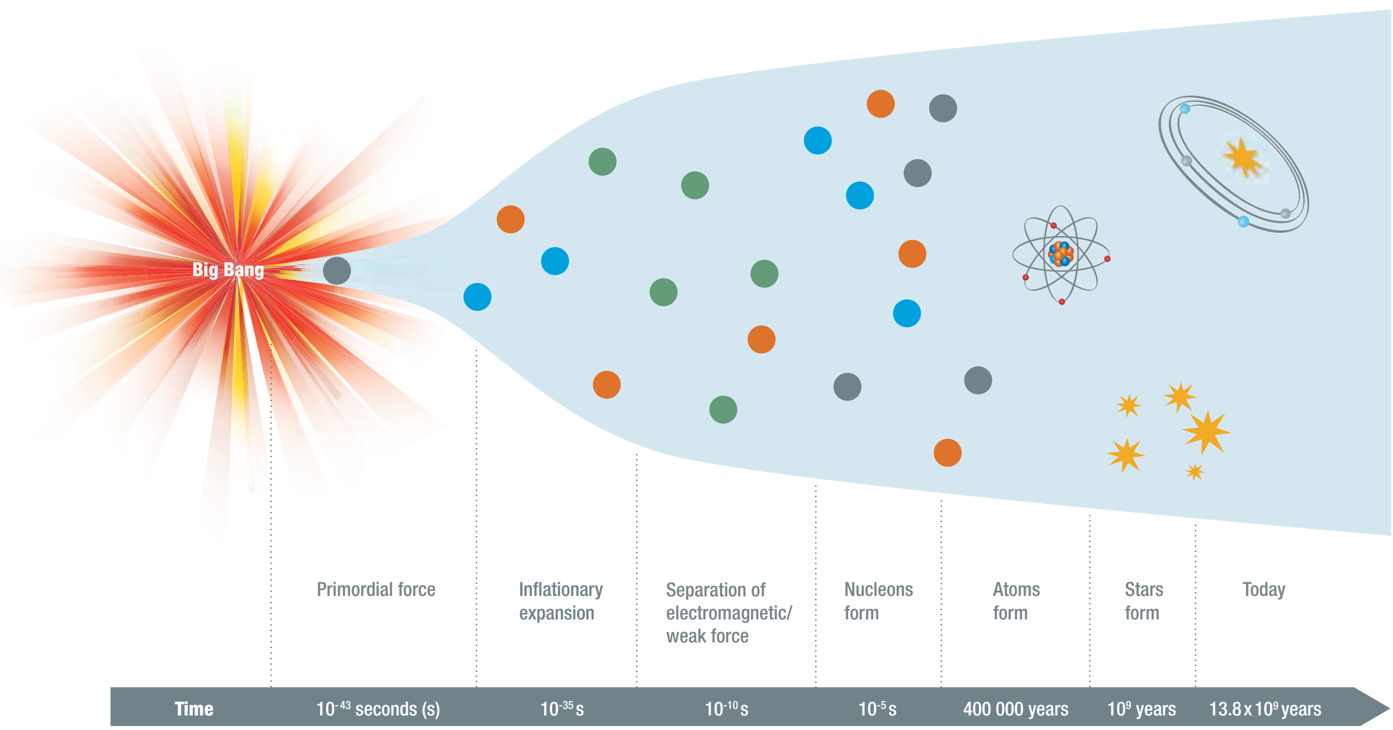
Is the universe completely symmetrical? Physicists are certainly tempted to think so, because symmetries have always served as reliable signposts in the past. They are the basis of Einstein's theory of relativity as well as of the Standard Model, which is the currently valid theoretical framework for particle research.

In their search for symmetry, scientists began to develop a new worldview in the 1970s – a theory that is far more symmetrical than anything seen before. This supersymmetry, or SUSY for short, is still only a hypothesis. But if it should prove to be correct, it would solve a number of riddles in the realm of physics at a single stroke. At the same time, it would bring researchers a big step closer to creating a unified and coherent model of the universe.

"The theory of supersymmetry is so convincing that it would be surprising if nature didn't make use of it."
Georg Weiglein, DESY

In daily life, symmetries are mainly apparent in images and shapes. Our reflection in the mirror is symmetrical, as are the patterns on butterfly wings and the geometrically arranged gardens of the Baroque age. In physics, by contrast, symmetries are mainly manifested in formulas and equations. "A ball looks the same no matter how you turn it," explains the physicist Herbert Dreiner from the University of Bonn. "Mathematically speaking, the ball is rotationally symmetrical."

Such abstract symmetries have been crucially important throughout the history of physics, and they are fundamental to our understanding of the material universe. This is impressively demonstrated by what is probably the most prominent scientific theory – Einstein's theory of relativity. "It is one of the main pillars of physics and is based on symmetries that link space and time," says theoretical physicist Georg Weiglein from DESY.



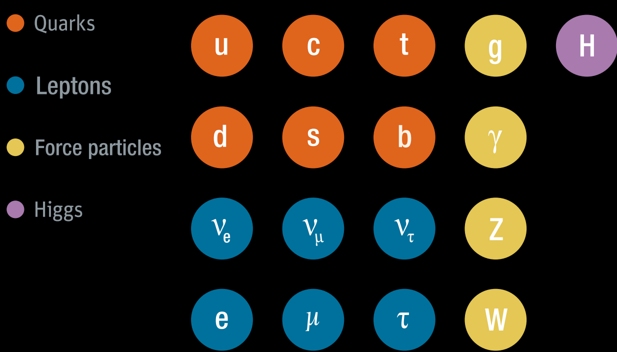
A brief history of the cosmos: Around 13.8 billion years ago, the Big Bang created innumerable elementary particles that came together to form atoms and eventually stars and galaxies. The Big Bang might also have created SUSY particles that still wander through the universe as dark matter.

Einstein's intellectual masterpiece is based on the principle that the laws of physics are identical everywhere and at all times. As a result, the speed of light is always the same – in Berlin and on the moon and last week as well as one hundred years from now. Einstein's formulas (including the famous $E=mc^2$) are highly symmetrical from a mathematical standpoint. Experts call this space-time symmetry an external symmetry.

As scientists gradually delved deeper and deeper into the microcosm and studied the quantum world of atoms and subatomic particles, they came across a further class of symmetries – the internal symmetries. These abstract constructs are behind the forces of nature that rule events in the microcosm. The electromagnetic force, which acts between electrons and atomic nuclei and controls all chemical processes, is one example.

The so-called conservation laws are a direct consequence of these internal symmetries, and are as important for particle research as they are convenient. For example, if an accelerator causes a fast electron to collide head-on with a positron (anti-electron), the collision creates exotic new particles that immediately decay. The total electric charge remains unchanged during the whole process. The charges of the electron and the positron add up to zero, so the sum of the charges of the newly created exotic particles is also zero, as is the sum of the charges of all the decay products.

However, the currently valid theory of particle physics, the Standard Model, largely treats internal and external symmetries independently of one another, creating a situation that is very unsatisfactory for researchers. "Several decades ago, somebody therefore asked whether there is a connection between the two," says Weiglein. "The answer to this question was supersymmetry, which is the only mathematical model that can reconcile internal and external symmetries in our four-dimensional space-time."



Particles and forces

The Standard Model of particle physics summarises our current understanding of the microcosm. It describes the basic building blocks of our world: Up and down quarks combine to create protons and neutrons, the components of atomic nuclei. Another elementary particle, the electron, forms the atoms' shells.

Electrons and quarks have heavy, unstable sister particles. They are created when cosmic radiation hits the Earth's atmosphere, for example, and quickly decay into stable particles. Neutrinos are extremely light and elusive particles that are created as a result of nuclear fusion in stars, for example. Even though huge numbers of neutrinos sweep through the universe, they hardly ever interact with matter.

The Standard Model also describes force particles, which mediate the forces of nature that interact between matter particles. In 2012, the model was rounded off by the discovery of the Higgs particle. The Higgs makes it possible for other elementary particles to possess mass.

The Standard Model has to date been impressively verified. However, it still leaves several key questions of physics unanswered:

Is there a deeper mathematical connection between the building blocks of matter and the force particles?

What is the composition of the dark matter that seemingly holds the galaxies together?

Why is the Higgs particle so incredibly light?

Are the various forces of nature in reality only facets of a single primordial force?

All of these questions could be answered by a theory that is still only hypothetical – supersymmetry, or SUSY.

Experts have been working on the corresponding theoretical framework since the 1970s, creating a number of different variants to date. The basic mechanism that underlies all of these varieties of SUSY is extremely abstract and not at all tangible. It has to do with one of the quantum properties of elementary particles – their spin. The spin can be visualised as the intrinsic angular momentum of the particle. Physicists distinguish between two types of particle: those with half-integer spin (e.g. spin ½) and those with integer spin (e.g. spin 1). Particles with half-integer spin are called fermions and serve as the building blocks of all matter. Particles with integer spin are called bosons and are responsible for transmitting all of the forces of nature that hold matter together. Put simply, fermions are matter particles, while bosons are force particles.

Supersymmetry incorporates spin into the usual space-time, creating a much more complex and abstract space-time in the process. All particles that move through this theoretical superspace acquire completely new properties – this concept goes far beyond particle physics' tried and tested Standard Model.

The main consequence of this superspace is that the conventional, known particles must have exotic new partners. For example, a quark, which is a fermion by nature, should have a squark as its counterpart – a supersymmetric quark from the world of bosons. Correspondingly, the selectron would be the counterpart of the electron, while the partner of the photon would be the photino, and of the gluon the gluino.

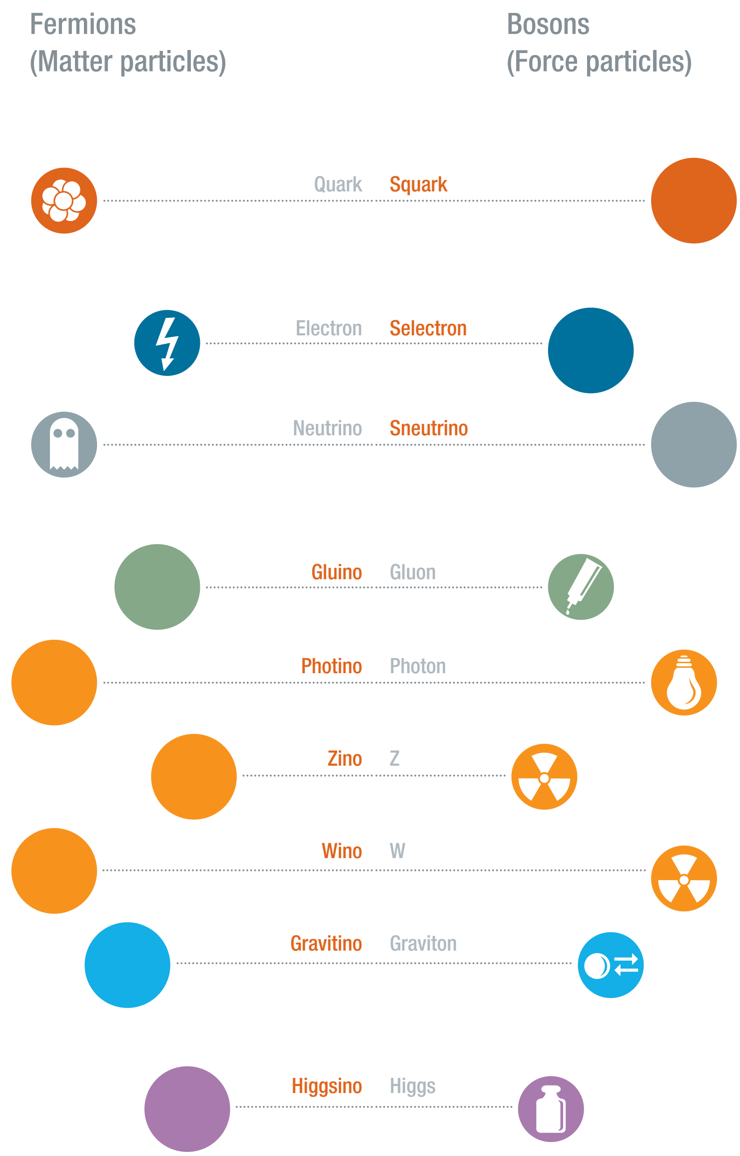
"SUSY suggests that all of the forces of nature we observe today arose from a single primordial force."
Herbert Dreiner, University of Bonn

The former partner in each of these pairs is a boson, the latter a fermion. Overall, supersymmetry would double the number of particles found in the Standard Model, creating a veritable shadow world of still hypothetical superpartners. However, the superpartners would have to be much heavier than the conventional particles; otherwise they would have been detected in accelerator experiments long ago.

But what would we gain from SUSY? How would it benefit particle research? For one thing, it would make the framework of nature more appealing and elegant than ever before. That was the intention of the theory's inventors, who wanted not only space and time, but also forces and matter to be symmetrical. From a mathematical point of view, this would create a highly symmetrical state.

After a while, it became apparent that SUSY would also result in other benefits. "In the Standard Model, the three fundamental forces of particle physics have different strengths," says Herbert Dreiner. "Supersymmetry suggests that the forces all had the same strength shortly after the Big Bang, which means they arose from a single primordial force." If that were the case, supersymmetry could be a milestone on the road to achieving one of physics' key goals – the unification of all fundamental forces. String theory is considered a possible candidate for such a comprehensive model of the universe. Because string theory can elegantly incorporate supersymmetry, today people generally refer to "superstrings".

Moreover, SUSY could potentially solve two specific mysteries of particle research. In 2012, scientists at CERN in Geneva discovered a new particle that seems to fulfil the requirements for the last missing piece of the Standard Model. Called the Higgs boson, it makes it possible for other elementary particles to have mass. Even after its discovery, the Higgs remains an enigma. "According to the Standard Model, it should be much heavier than it actually is," explains Dreiner. "Only supersymmetry can cogently explain why the Higgs is so light." An extremely heavy Standard Model Higgs would have had dramatic consequences for the universe, and the cosmos could not have developed in its current form.



A heavy shadow world: In supersymmetry, every known particle has a heavy counterpart. The superpartners of our matter particles are force particles. They are prefixed by an "s" so that a quark becomes a squark, for example. Conversely, the SUSY partners of the known force particles are matter particles. They have the suffix "ino" attached to their names. For example, the counterpart of the photon is the photino.

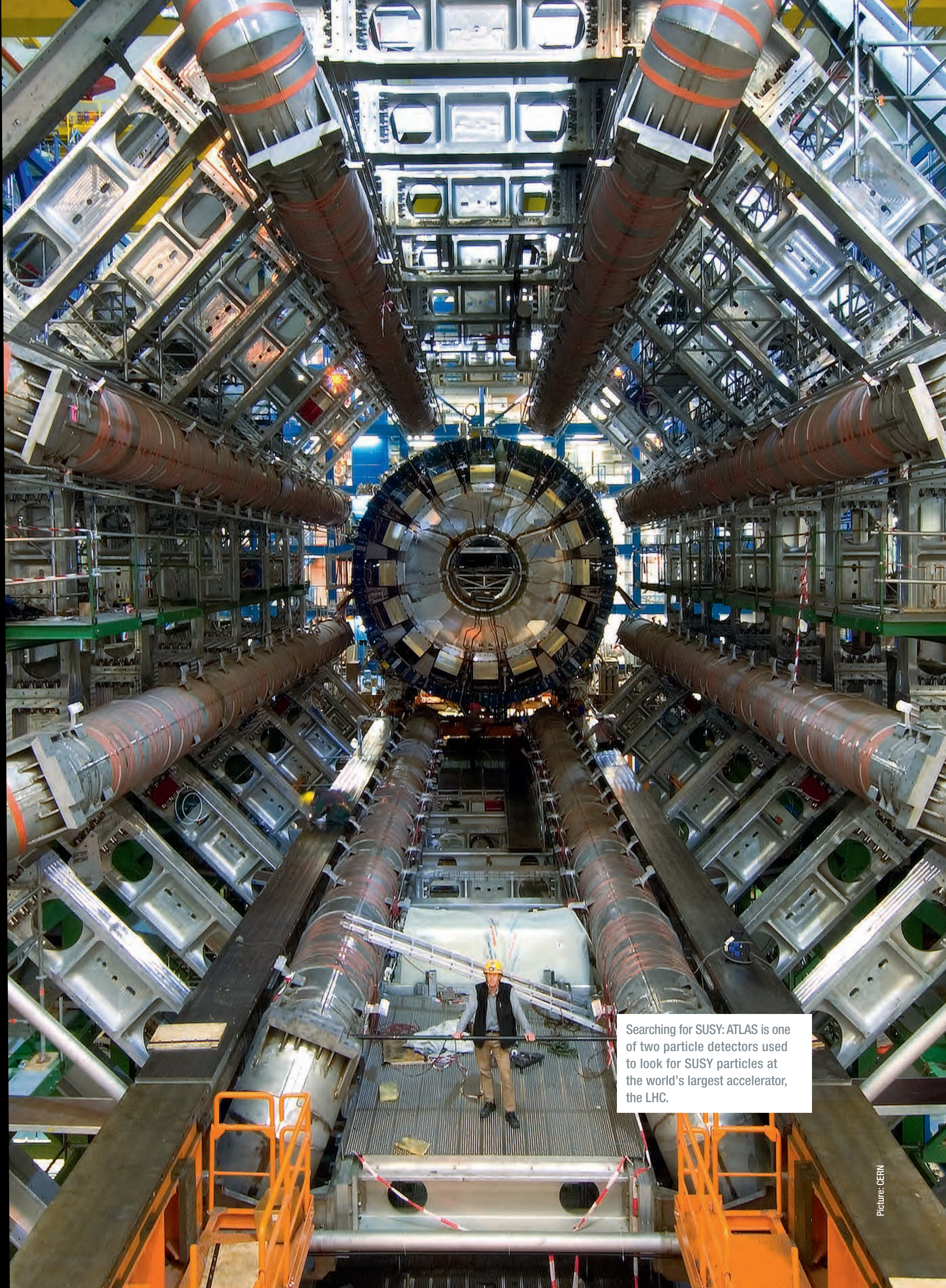
The second mystery that SUSY might be able to solve is that of dark matter. Although it has been calculated that dark matter should be around five times more common in the universe than conventional matter, it is still not known what dark matter is composed of. Supersymmetry would solve this riddle. "The lightest SUSY particle might be a neutralino, which is a stable particle that doesn't decay," says Weiglein. "That would make it a good candidate for dark matter."

If the theory of supersymmetry is correct, scientists would have a much better understanding of particle physics. Physicists would know which forces and particles are mathematically connected and why the Higgs particle is so light. They might also solve the mystery of dark matter and develop a theory that unifies the forces of nature. Yet to verify the theory, scientists would finally have to discover a SUSY particle in an accelerator.

The problem is that "the theory doesn't tell us how heavy the new particles should be," says Weiglein. As a result, it is not known how great the energies would have to be to create the particles – i.e. how strong an accelerator has to be so that SUSY can finally be verified. The next opportunity for its verification will come when the world's most powerful accelerator, the LHC, has completed its upgrade so that it can shoot particles at each other at unparalleled energies. "I'm confident that the crucial evidence will then be found," says Weiglein. "As some of my colleagues like to say, supersymmetry is just too beautiful to be wrong!"

Superstrings

What is matter made of at the most elementary level? Are the basic building blocks really the quarks and electrons found in the Standard Model? Many proponents of string theory claim that this is not the case. According to them, the universe is composed of immeasurably small strings. Like the strings of a violin, they can vibrate in different ways, creating the known particles in the process. The great attraction of this idea is that the strings would finally reconcile the two fundamental pillars of modern physics: quantum mechanics and the general theory of relativity. As a result, string theory could evolve into the legendary "theory of everything" – the comprehensive physics theory that Albert Einstein and Werner Heisenberg already worked on. Soon after the strings had been "invented", their creators noticed that supersymmetry's theoretical framework would be an ideal fit for their concept. As a result, the strings became superstrings. If SUSY particles should indeed be found, it also would be good news for the advocates of strings, because they would see the discovery as confirmation that they were on the right track with their theory.



Searching for SUSY: ATLAS is one of two particle detectors used to look for SUSY particles at the world's largest accelerator, the LHC.

Picture: CERN

Searching for SUSY

How physicists are using the world's largest accelerator to look for supersymmetry

The lift takes you 80 metres underground. After the door opens, you walk through plain concrete corridors and rooms until you suddenly stand in front of a huge high-tech block. Its name: ATLAS. Its vital statistics: 25 metres tall, 45 metres long, weighs 7000 tonnes and is composed of millions of individual components. ATLAS is one of two particle detectors used to look for SUSY particles at the world's largest accelerator, the LHC.

Isabell Melzer-Pellmann heads the CMS-SUSY group at DESY. She is confident that the LHC will discover supersymmetric particles.

ATLAS and CMS (the second detector) conducted an initial search between 2010 and 2012 without success. But following a two-year upgrade, the LHC will take up the search again in 2015 at energies that are almost twice as high as before. "The upgrade greatly increases the likelihood that we will be able to create supersymmetric particles," says Isabell Melzer-Pellmann, who heads the CMS-SUSY group at DESY. "And I'm confident that we will finally discover them."

The Large Hadron Collider (LHC) at CERN is the world's largest accelerator – an underground ring with a circumference of 27 kilometres. It accelerates protons (hydrogen nuclei) to extremely high energies and makes them collide with one another head-on. These collisions can give rise to short-lived exotic particles that immediately break apart into other particles. The detectors try to measure these fragments as accurately as possible as they fly away in all directions. The devices measure everything from flight path and momentum to energy and electric charge. On the basis of this measurement data, scientists can later reconstruct which elementary particles the collisions created and whether they included new, previously unknown exotic particles.

In 2012, this method enabled ATLAS and CMS to discover the Higgs boson, the last missing piece in the Standard Model of particle physics. The Higgs boson makes it possible for other elementary particles to have mass. Just one year later, Peter Higgs and François Englert, two of the inventors of the Brout-Englert-Higgs mechanism, received the Nobel Prize in physics. The LHC had achieved one of its goals. The other – the discovery of supersymmetric particles – has not yet been attained.

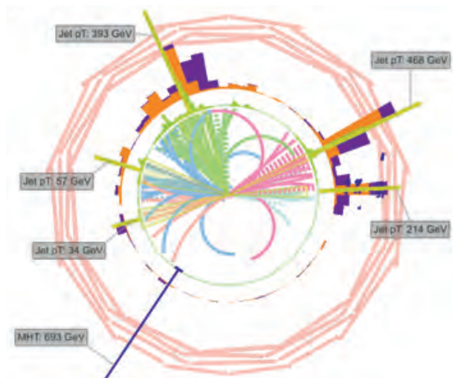
The search is difficult and time-consuming, because the experiments literally swamp the researchers with a flood of data. "You can compare our detector with an ultrafast digital camera that takes 20 million pictures per second," explains Philip Bechtle, a particle physicist from Bonn and one of the approximately 3000 researchers involved in ATLAS. "If we wanted to record all of the signals, we would have to store one petabyte of data every second." That's enough data to fill 200 000 DVDs per second.

Because doing so would be a technical impossibility, sophisticated electronics filter out the measurements that probably contain no new findings but only familiar information. Huge amounts of data are nevertheless left over. Around 200 events are recorded every second, creating a total data volume of one gigabyte. Almost 100 hard discs would be needed each day to store this data.

From this mass of data, physicists have to find the few interesting particle tracks that hint at the brief existence and decay of a SUSY particle. "There are one billion uninteresting events for every interesting one," says Melzer-Pellmann. The researchers are specifically looking for special patterns in the detector that could reveal the supersymmetric particles.

As an example, an exotic SUSY particle that was created in the LHC could break apart along a decay chain until it is transformed into the lightest SUSY particle. In many SUSY models, this particle would be the neutralino, which is also a good candidate for the dark matter in the universe. "Although the neutralino would be stable, our detector wouldn't be able to find it, because it hardly interacts with matter," explains Melzer-Pellmann. "However, we would notice that energy suddenly went missing." This missing energy would be powerful evidence of the new particle's existence.

To show how such a possible key event would unfold, Melzer-Pellmann points to an image on her PC. It depicts a CMS diagram interspersed with colourful lines that symbolise the particle tracks – a snapshot of a collision. "While many fragments fly upward, very few are registered going downward," she says. "A neutralino – a SUSY particle – might have flown that way without interacting with our detector."



Particle tracks after a collision

That's how it should be in theory, but recognising such clear patterns in the measurement data is difficult in practice. This is because familiar particles can create very similar events that feign a SUSY signal. To find the characteristic SUSY signature amid the huge amount of background noise, researchers need to use clever analysis methods and evaluate an extremely large amount of data.

The hunt has been unsuccessful so far – at least during the LHC's first operating phase from 2010 to 2012. "We failed to find even the slightest hint of supersymmetry," says Klaus Mönig, who is one of the heads of the ATLAS group at DESY. "That's pretty disappointing, since the theoretical physicists' predictions had suggested that we might be able to find something."

It therefore seems that certain variants of SUSY have already been ruled out. Supersymmetry isn't a compact, self-contained model, but rather a theoretical framework that is somewhat flexible. Within this framework, theoretical physicists have developed a number of different SUSY variants over the years. Some of these variants are – relatively – simple, while others are more complex.

The simple theories assumed that the SUSY particles would be relatively light. If that were the case, the LHC should already have discovered them. "Nature doesn't seem to make things that easy for us," says the theoretical physicist Herbert Dreiner from Bonn. "But supersymmetry hasn't failed yet – perhaps the more complex variants are correct, which allow particles to be heavier as well." In its second operating phase, the LHC will be looking for these heavier SUSY particles.

Klaus Mönig heads the ATLAS group at the DESY location in Zeuthen. He already searched for hints of supersymmetry during the LHC's first operating phase.

A few days after the LHC was originally launched in September 2008, an electric fault caused ultracold helium to evaporate with explosive force, tearing several accelerator magnets from their mountings. As a precautionary measure, CERN allowed the LHC to only operate at half capacity after it was repaired. The energy output was initially limited to 7 teraelectronvolts (TeV) – a figure that was later raised to 8 TeV. The ring was upgraded starting in 2013 so that it will now be able to achieve a much higher collision energy of 13 TeV.

Although there are good reasons why we should be able to find supersymmetry in the coming years, there is no certainty

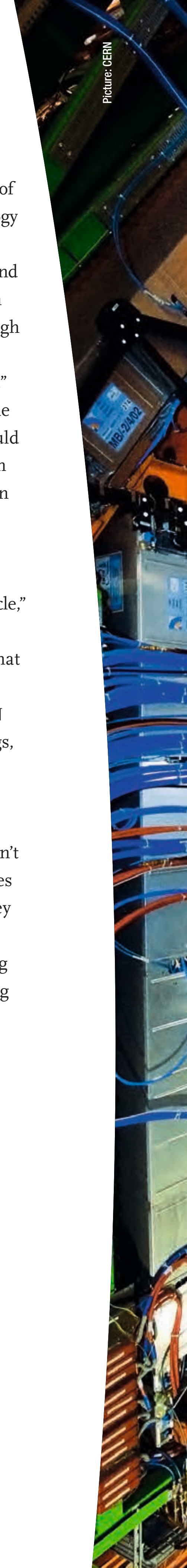
This upgrade is crucial because the greater the energy at which the protons collide, the heavier the particles that can be produced. “We are very hopeful about the next phase because it will open up a completely new range,” says DESY theoretical physicist Georg Weiglein. “Although there are good reasons why we should be able to find supersymmetry in the coming years, there is no certainty.”

But what if even the upgraded super-accelerator discovers no signs of SUSY? Some experts would certainly be very upset. “The theory would be dead, as far as I’m concerned,” says Dreiner. “I would then take on new challenges.” Other scientists would be unperturbed, however, and continue their search for supersymmetry. They are therefore calling for a further LHC upgrade in ten years, after which the machine would be able to provide far more measurement data and correspondingly increase the likelihood of a discovery.

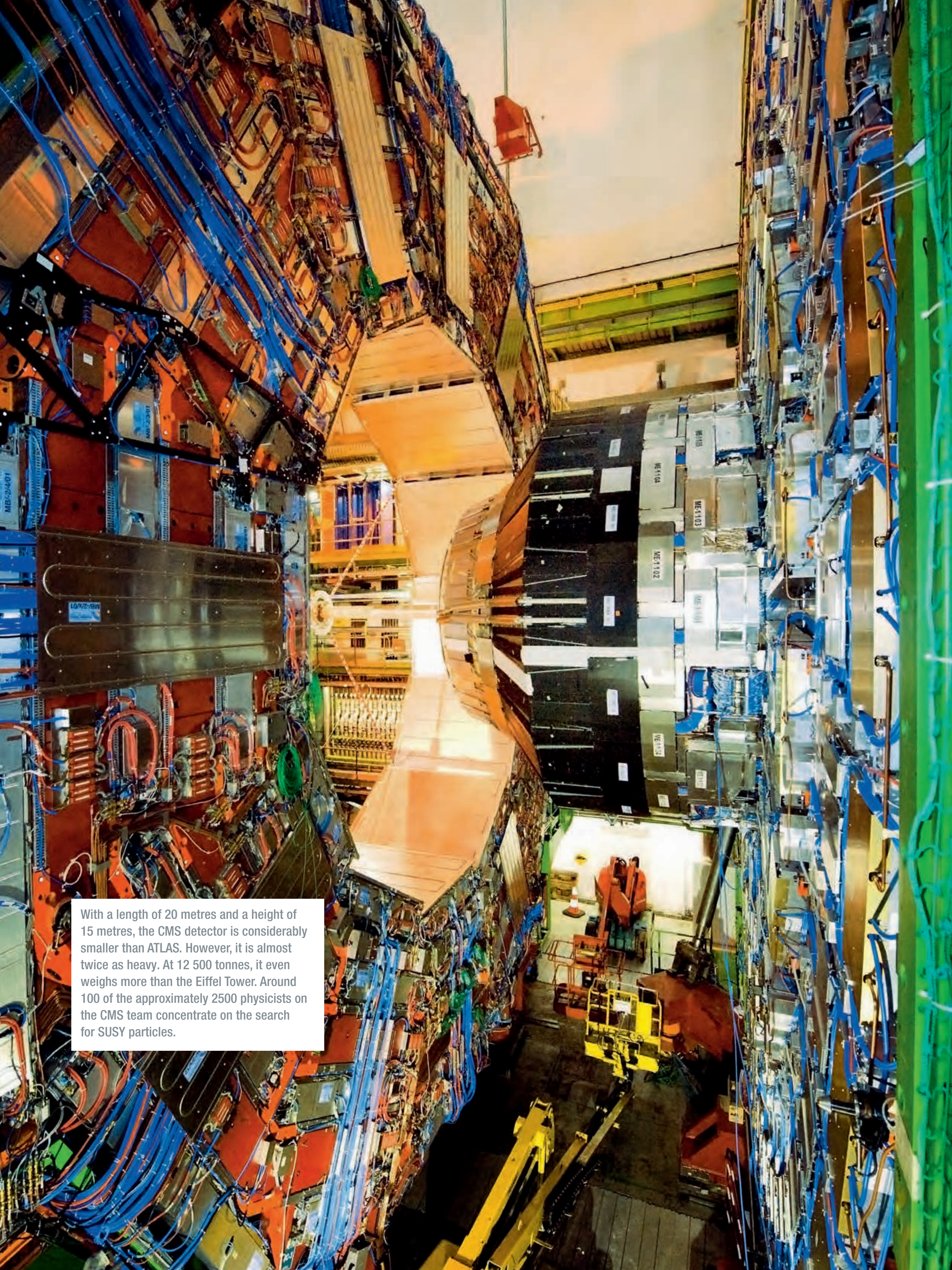
Some physicists are toying with the idea of using an alternative accelerator technology that would not shoot protons at one another, but the much lighter electrons and their antiparticles, the positrons. “Such a facility couldn’t achieve energies as high as the LHC, but the collisions could be analysed with much greater precision,” says DESY physicist Karsten Büßer. The scientists hope that such a facility would finally enable them to discover a certain type of SUSY event that is simply lost in the huge flood of LHC data.

“An electron–positron accelerator could also take a closer look at the Higgs particle,” explains Büßer. “We might even find deviations from the Standard Model that could be best explained with SUSY.” For example, it’s possible that in 2012 CERN discovered not the Standard Model Higgs, but a supersymmetric Higgs.

But even if none of the experiments find any signs of SUSY, the theory still wouldn’t be disproved. “Supersymmetric particles could, in principle, be so heavy that they could never be found,” says Weiglein. SUSY would then always remain nothing but a theory – mathematically appealing and elegant, but of no practical use.



Picture: CERN



With a length of 20 metres and a height of 15 metres, the CMS detector is considerably smaller than ATLAS. However, it is almost twice as heavy. At 12 500 tonnes, it even weighs more than the Eiffel Tower. Around 100 of the approximately 2500 physicists on the CMS team concentrate on the search for SUSY particles.

The search for clues

If the search for SUSY particles with an accelerator is unsuccessful, it will still be possible to confirm their existence through circumstantial evidence. The reasoning is that if an experiment delivers results that can no longer be explained by means of the Standard Model but can be explained through supersymmetry, the theory will be considerably reinforced. There are several approaches to finding such indirect evidence.

1. Looking out for dark matter

Several experiments in different parts of the world are searching for the particles that are suspected to be behind dark matter. Most of these experiments are being conducted in laboratories deep beneath the Earth's surface or within mountains so as to be shielded from disruptive external influences. If a dark-matter particle were to collide with the detector's crystal grid, this would create a weak signal. The search has been unsuccessful so far, but if such an exotic particle were actually found, it could be a SUSY particle.

2. Examining the magnetic moment

When US researchers precisely measured the muon – a particle similar to the electron – a few years ago, they made a surprising discovery: the particle's magnetic field deviated slightly from the value predicted by the Standard Model. One possible explanation was that the muon could have briefly transformed itself into its superpartner, the smuon. However, the measurement data are not completely convincing, so physicists in Chicago want to repeat the experiment with greater precision starting in 2016.

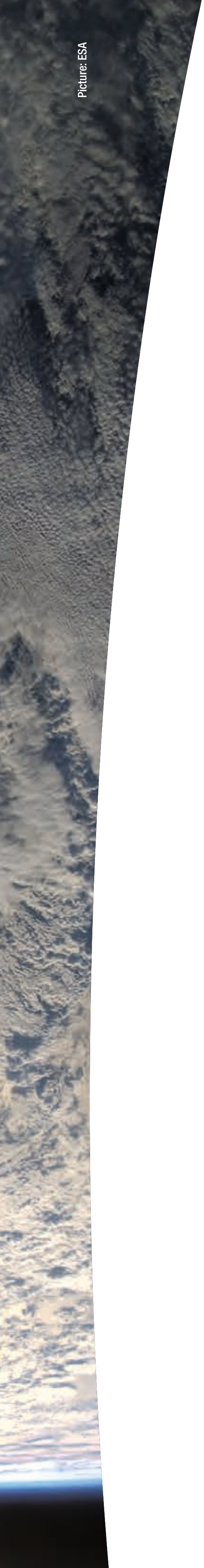
3. Searching for clues at the South Pole

The approximately 5000 light sensors of the IceCube experiment are buried deep in the Antarctic ice sheet. The sensors' main function is to detect signals from neutrinos – elusive particles that come from the far reaches of space and only seldom interact with matter. But IceCube may also be able to observe the signals of SUSY particles. These should be regularly generated when energy-rich cosmic particles hit the Earth's atmosphere with tremendous force. Some of these SUSY particles are expected to hit IceCube and leave telltale traces of light.

4. Hunting for hints in space

A particle detector called AMS has been installed on board the International Space Station since 2011. AMS counts antiparticles and tries to find out how much antimatter exists in space. The initial results were surprising: AMS had captured more positrons than expected. These may have originated in pulsars, which are rapidly rotating neutron stars. It could also be that wandering dark-matter particles are colliding and sending out the positrons. Only future measuring data can determine which of these assumptions is correct.

The International Space Station ISS



Physics beyond the Standard Model

Rolf Heuer, the Director-General of CERN, talks about the potential of the LHC, which is searching for new particles at much higher energies

femto Rolf Heuer, you've been the Director-General of CERN since 2009. That means you've been there for the entire time the Large Hadron Collider, or LHC, has been operating. At the start of the project, what did the scientists expect to find?

Heuer I think almost everyone hoped they would soon find particles of dark matter, and thus supersymmetry. That's because the cross section, or in other words the probability of generation, of dark matter is relatively high and its signature is relatively clear. Many people thought we would discover supersymmetry practically overnight. That was of course a naïve notion, and nature decided differently. If supersymmetry exists at all, it lies somewhere else.

femto Instead, in 2012 you made the sensational discovery of the Higgs particle. What happens next? What are your expectations for the years ahead?

Heuer The same ones we had three years ago. That is, at some time we have to find supersymmetry or some other indication of physics beyond the Standard Model. After all, the Standard Model can't be the final word on the subject. Let me give you an example.

Rolf Heuer, Director-General of CERN

In our daily life, we basically deal only with Newton rather than with Einstein (unless we use GPS – if we forget Einstein in that connection, we might land in the river Elbe instead of getting to the Fischmarkt in Hamburg). In other words, Newton is a low-speed approach to Einstein. That's how I regard the Standard Model – as the low-energy approach to something that is out there around it and includes the Standard Model as an approximation. We have to find this larger entity someday. That's my hope.

femto When will that happen?

Heuer I simply can't say. In the first place, that depends on the mass of the particles, and secondly on the strength of the coupling – in other words, how frequently the particles are generated and where the new scale lies. If the scale is very distant, there might be only very small effects. In the years ahead, the key factors will be the increase in energy at the LHC and the precision measurements – in other words, the large statistics.

femto What do you mean when you say "discover supersymmetry"? How exactly does this happen?

Heuer It means we find new particles with the characteristics of supersymmetric particles – that is, with the corresponding decay chains. As a rule, we don't generate the particle with the smallest mass, but rather a number of particles with higher masses, which then decay into the lightest particles. According to many theories, this lightest particle is stable. It acts more or less like a neutrino in that it can't be identified in the detector, which means we can't see it. But of course we see the missing energy that this particle takes with it, and the absent momentum. As a result, with the detectors we can reconstruct the decay chain and then compare it with the big matrix of supersymmetric models. And when we do that, we find a place where things fit.

femto How many particles do we need to have in order to be able to say we know something for sure?

Heuer The question is: What does "sure" mean? How sure can one be? I think that when you find a particle that does not fit into the Standard Model, you can be sure that it is part of physics outside the Standard Model. Every new fundamental particle that is added to the picture is beyond the Standard Model. I'm absolutely sure of that. I'm not sure exactly what it might be. But I do know that now I've found a gap in the Standard Model.

femto And what if there's nothing?

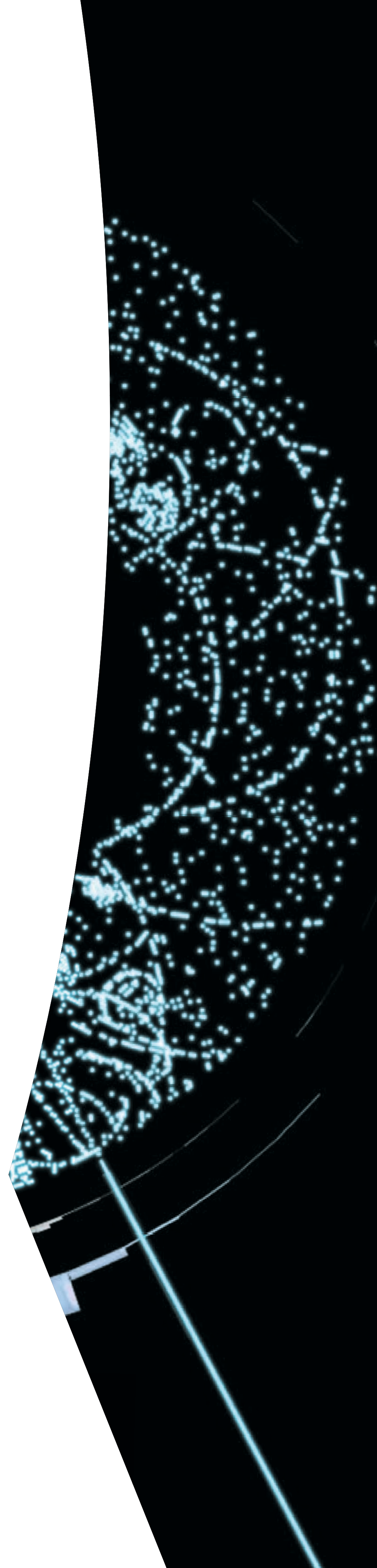
Heuer In that case, we'll simply go on measuring until we find something. If we find nothing at all in the next few years, we will at least have an idea of how distant the scale is that would include the new physics. And then there is also the question of whether there are other measurements that could take us a bit further – highly precise measurements that would give us an impression of the deviation from the Standard Model. Especially if we don't find any new particles at first, high precision is absolutely necessary, and for that we need different methods.

femto What's the next step after the LHC and after the next discovery?

Heuer That depends on the discovery. At the moment, we are keeping all the options open at CERN for future accelerators: proton–proton, electron–positron and electron–proton, circular or linear. The next few years will have to show us, through the results from the LHC, from astroparticle physics and from other facilities, the direction in which we should go.

femto In the history of particle physics, each discovery has generally brought the next question with it. Will things develop that way here as well?

Heuer What will be the next question? Of course we already know one question – what is dark matter? But the next question is: what energy do we need in order to decode it? We have to get a sense of how to answer this question. We can't simply say that we need the next high-energy accelerator. But if we have a good project and all of us support this project, we will also manage to realise it.



Grand unification

Physicists would like nothing more than to be able to explain everything. They would like to have an elegant theory that brings together all of their knowledge in a comprehensive model. This theory would reach back to the origins of the universe and also answer the big question of whether the familiar forces of nature are merely different forms of a single mighty "primordial force". Moreover, the theory would even be able to finally unify the force of gravity with the other forces.

Joachim Mnich, director of particle physics at DESY

"But is nature really so simple that there is ultimately only a single force?" asks Joachim Mnich, the director in charge of particle physics at DESY. "We won't be able to answer this question anytime soon. However, we might get hints in the coming years that will tell us where it's worthwhile to look." Mnich knows from decades of experience that the long road to the "theory of everything" is made particularly exciting by the many small yet challenging steps it involves.

For example, the discovery of the Higgs particle in 2012 was not only a glorious confirmation of the very successful Standard Model of particle physics, but also a crucial step towards opening the door to a new physics that extends beyond this model. "In the years ahead, we will measure the properties of the Higgs particle as precisely as possible," says Mnich. "Should we discover tiny deviations from the predicted values, this could be crucial evidence of a previously unknown physics that would expand our worldview beyond the models that have been verified to date."

One of the really big questions is the nature of dark matter

This research might uncover the avidly looked-for supersymmetric particles – or something completely different. "One of the biggest questions is the nature of dark matter," explains Mnich. That's because the successful Standard Model of particle physics explains only the five percent of the matter in the universe that we are familiar with. Astronomers have observed another kind of matter, one that isn't visible and is only revealed by its gravity. Even though this dark matter is five times more common than the matter we are familiar with, its nature is a complete mystery. Many physicists hope that the LHC superaccelerator will discover possible candidates for dark matter.

"Unfortunately, we don't even know if dark matter consists of particles," says Mnich. "We know that dark matter interacts with other matter through gravity. We hope that it is also subject to the weak interaction, which is responsible for radioactive decay, among other things. If this is not the case, it will be very hard to find particles of dark matter in an accelerator." Supersymmetric particles are also possible candidates for dark matter.

It's an exciting challenge to keep on stretching the boundaries of our perception and imagination

But even if physicists should discover anything about the nature of dark matter, they still won't be able to thoroughly explain the cosmos. That's because more than two thirds of the content of our universe consists of a mysterious dark energy, which seems to be pushing space itself apart. Astronomical observations have detected this dark energy, but scientists still have no clue as to what it might be.

The search for the causes of the surprising asymmetry between matter and antimatter is more concrete. The Big Bang should have produced equal amounts of matter and antimatter. However, there is almost no trace of antimatter left in today's universe. "Many experiments are being conducted worldwide to find the cause of this asymmetry," explains Mnich. "DESY is extensively involved in the Belle II experiment in Japan, for example." The Japanese KEKB ring accelerator is currently being converted into a "factory" for B mesons, which are particularly useful for studying this asymmetry. The basis for such B-meson factories was laid by facilities including DESY's DORIS storage ring, where in 1987 the ARGUS detector enabled researchers to observe the transformation of a B meson into its antiparticle, an anti-B meson, for the first time.

"The antimatter experiments are very exciting," says Mnich. "For example, CERN has managed to create anti-hydrogen – an antiproton around which a positron orbits. Experimenting with it is extremely fascinating! For example, nobody has so far measured precisely how antimatter behaves when it is subject to gravity. Does anti-hydrogen perhaps fall upwards? It's an exciting challenge to keep on stretching the boundaries of our perception and imagination!"

It's clear, however, that the next steps towards the development of a "theory of everything" are a global challenge. "International cooperation has a long tradition in particle physics," says Mnich. "DESY is extensively involved in a variety of major projects looking for SUSY particles and other possible candidates for dark matter. Although the experiments at the LHC are of course an important focus, DESY also concentrates on areas such as astroparticle physics."

One of DESY's particular strengths continues to be the analysis of proton structure, the thorough understanding of which is crucially important for future Higgs research at the LHC. This accelerator collides protons with other protons, and the collisions do not provide a clear picture unless we know in detail what is colliding with what. Nowhere has the interior of the proton been more precisely investigated than at DESY's HERA accelerator.

But simply carrying out experiments is not enough. "We also have to understand the experiments," Mnich points out. "You need a theoretical basis to do that. The crucial thing is to combine the results of accelerator experiments with those of astronomical observations. At DESY, we have an extremely effective theory group with an outstanding reputation worldwide. This group also offers a unique environment for up-and-coming young scientists."

And what will happen over the next few years? "It's hard to say what the world of particle physics will look like five years from now," says Mnich, who is also the new chairman of the International Committee for Future Accelerators (ICFA). "The LHC with almost twice its previous energy presents unique potential. But to really understand particles such as the Higgs, we also need an electron–positron accelerator. This would serve as a kind of Higgs factory, which would enable comprehensive high-precision measurements. DESY has an incredible amount of expertise in accelerator-based particle physics and will play a crucial role in all of this. I'm really looking forward to it!"

Picture: iStock

New business incubator on the DESY campus

Hamburg's Senate, DESY and the University of Hamburg create attractive environment for start-ups

Young, innovative companies will soon be benefiting from the outstanding infrastructure and scientific expertise on offer at the DESY campus in Hamburg. A new business incubator is to be built on a site of over 5000 square metres right next to the campus. It will feature offices, laboratory facilities and a start-up office providing consultation for fledgling enterprises. As Olaf Scholz, Hamburg's First Mayor, explains: "This new innovation centre is the latest step in our strategy to turn the Bahrenfeld campus, in partnership with many other participants, into one of the world's leading locations for structural research. There can be very few, if any, research locations, either in Germany or abroad, that are currently developing with the same dynamism."


Picture: DFZ Architekten / DESY

Architectural drawing of the planned innovation centre

With the new business incubator, DESY and the University of Hamburg further boost their activities to promote knowledge and innovation transfer. Partially funded with an investment grant of 14.2 million euro from the Free and Hanseatic City of Hamburg, the new start-up centre is targeted at prospective and existing spin-offs from DESY and the University of Hamburg, as well as small technology companies already in business.

A number of DESY spin-offs are already in operation: X-Spectrum develops, constructs and markets X-ray detectors originally developed at DESY, along with the corresponding software; suna-precision GmbH develops and markets special high-precision equipment for use in X-ray experiments; and Class 5 Photonics, a joint spin-off from DESY and the Helmholtz Institute Jena, constructs highly versatile femtosecond lasers delivering short, high-power pulses.

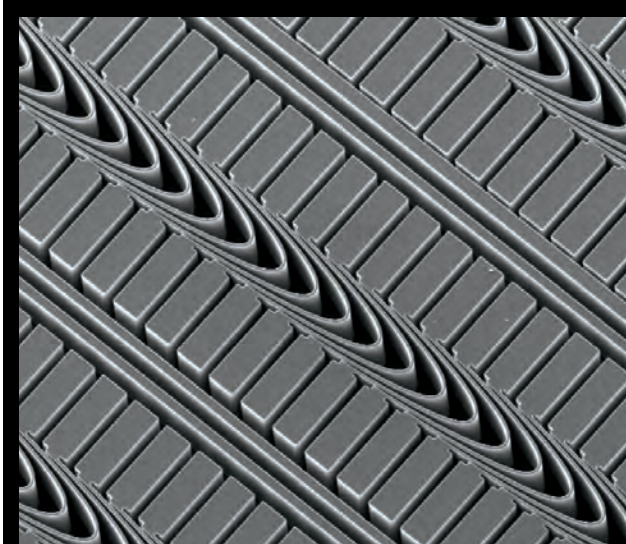
Researchers develop new type of X-ray lens

Researchers at DESY have made an important breakthrough in developing a new type of X-ray lens made of diamond. A team of scientists from DESY and the technical universities of Dresden and Chemnitz have successfully tested a new lens design.

Using bright X-ray light sources such as DESY's PETRA III facility, scientists study a variety of materials – ranging from biomolecules to solar cells and artificial magma – in order to explore their internal structure. In such studies, it is often necessary to focus the intense X-ray light. "In X-ray microscopy, the spatial resolution is often limited by the X-ray optics and not, as in optical microscopy, by the wavelength of the light used," explains Christian Schroer, scientific head of PETRA III.

X-rays cannot be focussed with conventional lenses in the manner of visible light. Instead, scientists use specialised lenses for this purpose, which currently are made of silicon. Schroer's team has now devised a new type of lens. Rather than having a concave profile, it is made up of fine, curved lamellae, which focus the X-rays.

Applied Physics Letters, 2014; DOI: 10.1063/1.4896914


Picture: Frank Seiboth / TU Dresden

Scanning electron microscopy image of the novel lamellar lens. Each lamella is about 1.5 micrometres (millionths of a metre) thick.

Every electron counts

FLASH X-ray laser study shows flaw in understanding of solids

Despite years of extensive research, many of the unusual electric, thermal and magnetic properties of modern materials remain a mystery. A study conducted at DESY's free-electron laser FLASH has now concluded that a flaw in current theories of solids hinders further understanding of complex material behaviour.

The new study questions the common assumption that individual electrons have little influence on a material's properties. It establishes that even minuscule changes of electric charge in a solid can have a major impact. This unexpected result may help demystify high-temperature superconductivity along with other unexplained phenomena in modern materials, and thereby make it possible to create complex material properties at will and exploit them in useful applications.

It is almost 30 years since high-temperature superconductors were first discovered, but scientists still don't understand how they work. Below a certain temperature, high-temperature superconductors conduct electricity without loss and may therefore one day be used as energy-saving materials in everyday applications.

Physical Review Letters, 2014; DOI: 10.1103/PhysRevLett.113.067001

Still liquid at minus 46 degrees Celsius

X-ray laser probes structure of supercooled water

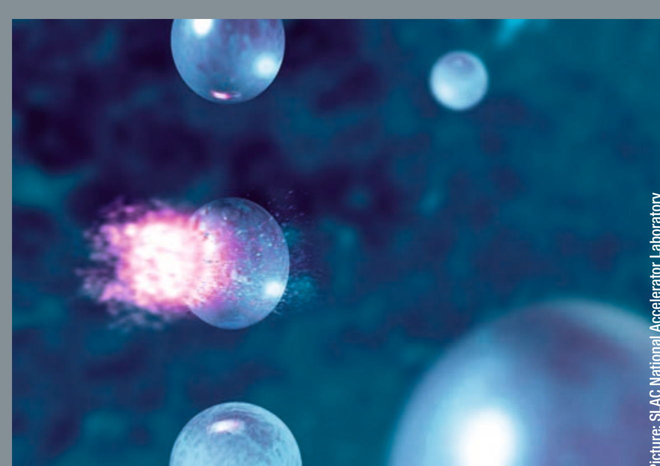
For the first time, scientists have investigated the inner structure of liquid water supercooled to a temperature of minus 46 degrees Celsius. A team led by Anders Nilsson from the SLAC National Accelerator Laboratory in the US used the lab's Linac Coherent Light Source (LCLS) to conduct a study which shows that the structural ordering of supercooled water increases continuously with falling temperature. These observations provide a first glimpse of a largely uncharted "no-man's land" in the phase diagram of water.

"Water is not only essential for life as we know it, but also has very strange properties compared to most other liquids," explains Nilsson. One example is the density anomaly that makes frozen water (ice) lighter than liquid water, with the result that it floats. Usually, water freezes at zero degrees Celsius. But very pure water with nothing in it to seed the formation of ice crystals can remain liquid at temperatures far below the normal freezing point. This is known as supercooled water.

"Scientists had known for long that water can remain liquid at extremely cold temperatures, but it has not yet been possible to obtain reliable structural information for liquid water below about minus 38 degrees Celsius," says DESY scientist and study collaborator Anton Barty from the Center for Free Electron Laser Science (CFEL).

At such extreme temperatures, even supercooled water remains liquid for only fractions of a second before it suddenly turns to ice. Using the ultrashort and superbright X-ray laser flashes of the LCLS, the researchers were now able to observe the internal structure of supercooled water at temperatures as low as minus 46 degrees Celsius. The results show that the structural ordering of supercooled water increases ever-more strongly with falling temperature. Nilsson hopes to reach even colder temperatures so as to see if the unusual properties of water peak at a certain point. "Our aim is to follow these dynamics as far as we can," he says. "Eventually our understanding of what's happening here in 'no-man's land' will help us fundamentally understand water under all conditions."

Nature, 2014; DOI: 10.1038/nature13266



Picture: SLAC National Accelerator Laboratory

Artist's representation of an LCLS X-ray flash hitting a supercooled water droplet

Lipid molecules in motion

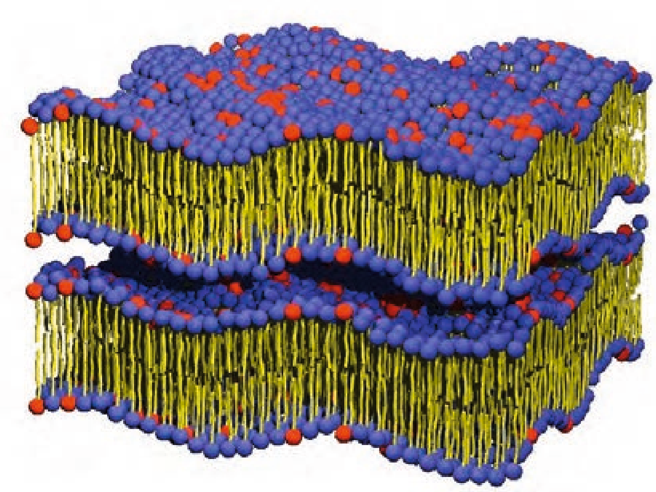
X-ray stroboscope sheds new light on biomolecular dynamics

Researchers at DESY have recorded the movement of lipid molecules using an X-ray stroboscope. The study offers new insights into the dynamics of special biomolecules that make up a variety of materials, including cell membranes. The latter consist of a double layer of lipid molecules and control the exchange of substances in living cells.

The researchers led by Tim Salditt of the University of Göttingen used ultrasound to induce controlled vibrations in a stack of lipid membranes. With the aid of the PETRA III X-ray source, they were able to observe that this not only makes the membranes vibrate like a drumhead but also causes the microscopic structure to oscillate. "Those membranes consisting of lipid bilayers changed periodically both in thickness and density under the influence of the externally induced motion," explains Tobias Reusch from the University of Göttingen.

"Similar structural changes could also result in the membranes of biological cells from a temporal fluctuation of forces," Salditt adds. "Visualising the changes in molecular structure with our stroboscope method makes possible new insights regarding the dynamic properties of this 'soft matter'."

Physical Review Letters, 2014; DOI: 10.1103/PhysRevLett.113.118102



Picture: Tobias Reusch, Tim Salditt / University of Göttingen

Excitation of a stack of lipid membranes by ultrasound leads to collective oscillations.

Photosynthesis in action

First observation of the molecular dynamics of photosystem II

An international team of scientists, including researchers from DESY, has been able for the first time to capture a key stage of photosynthesis as it actually happens. The team led by Petra Fromme from the Arizona State University used the world's most powerful X-ray laser at the SLAC National Accelerator Laboratory in the US to record still frames of the molecular complex known as photosystem II, which under the influence of sunlight splits water into hydrogen and oxygen.

Picture: Mary Zhu / Arizona State University

Sunlight-driven photosynthesis is the energy source of all green plants.

"This is the very first scene of a molecular movie showing light-driven water-splitting in photosystem II, the mechanism that makes all oxygen in the atmosphere," emphasises Fromme. The images show with molecular resolution that photosystem II significantly changes shape during this process.

"A deeper understanding of photosynthesis could, for instance, aid the development of better solar cells and might advance the quest for biochemistry's holy grail, artificial photosynthesis," says DESY scientist and study collaborator Henry Chapman from the Center for Free-Electron Laser Science (CFEL).

Nature, 2014; DOI: 10.1038/nature1345

DESY and IBM develop big-data architecture for science

DESY and IBM are collaborating on a new architecture for the storage of large volumes of research data. DESY is to use an IBM system capable of handling huge amounts of data extremely quickly. An X-ray light source such as DESY's PETRA III enables scientists to investigate the atomic structure of a whole range of materials, including new types of semiconductors, catalysts and biological cells. In the process, massive amounts of data are produced, all of which must be reliably handled and stored.

To meet this challenge, DESY and IBM Research are developing a solution based on the IBM software-defined storage system code-named "Elastic Storage". This upwardly scalable solution will be able to handle and store the 20 gigabytes of data per second generated by the PETRA III measuring stations at peak operation and provide researchers with faster access to their measurement data for analysis.

The solution's scalability will enable DESY to meet even greater data-handling challenges, not least for the European XFEL, an X-ray laser currently being built by DESY and various international partners. This research light source will generate substantially more data than PETRA III.

"We anticipate about 100 petabytes a year – that's 100 million gigabytes – from the European XFEL," explains Volker Gülzow, head of DESY IT. That is comparable to the annual data volume produced at the world's largest particle accelerator, the Large Hadron Collider (LHC) at the CERN research centre near Geneva.

"IBM's software-defined storage technologies can provide DESY with the scalability, speed and agility it needs to offer a real-time analysis service," says Jamie Thomas, General Manager Storage and Software Defined Systems at IBM. "IBM can take the experience gained at DESY and transfer it to other fields of data-intensive science, such as astronomy, climate research and geophysics, to design storage architectures for the analysis of data generated by distributed detectors and sensors."

Picture: DESY

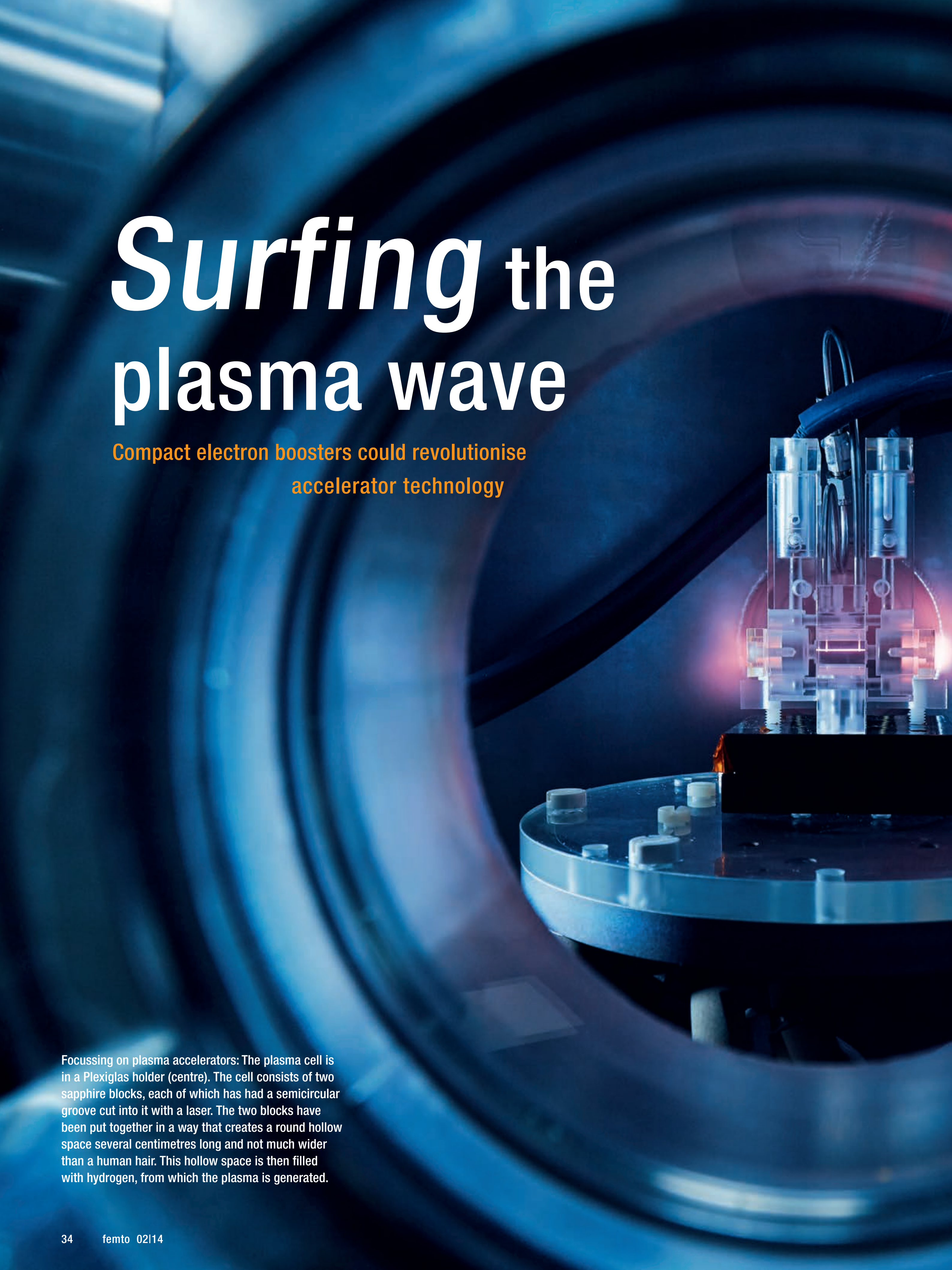
Inside the DESY computing centre

FEMTOMENAL

Big data

5 368 709 120 bits per second

That's the data flow generated by a modern X-ray detector – about the equivalent of a full CD-ROM every second. There is, however, more than one detector at DESY's X-ray source PETRA III. At present, it has 14 beamlines, and in future there will be 24, each equipped with new and even more powerful detectors. The DESY computing centre currently handles up to 20 gigabytes of data per second solely from PETRA III. That's the equivalent of 31 CD-ROMs every second.



Surfing the plasma wave

Compact electron boosters could revolutionise accelerator technology

Focussing on plasma accelerators: The plasma cell is in a Plexiglas holder (centre). The cell consists of two sapphire blocks, each of which has had a semicircular groove cut into it with a laser. The two blocks have been put together in a way that creates a round hollow space several centimetres long and not much wider than a human hair. This hollow space is then filled with hydrogen, from which the plasma is generated.

Ever smaller and more compact, and at the same time extremely powerful – this trend not only dominates consumer electronics but is also leading to new perspectives in research. The more we deepen our understanding of the ultrafast interactions between electrons, atoms and molecules, the more feasible ultrasmall applications become – applications that seemed utopian just a few decades ago. Even the kilometre-long particle accelerators of today, which are among the biggest scientific machines in the world, could someday be replaced by compact devices containing accelerator elements that are measured in centimetres. This could become possible through a technology that is based on an exotic state of matter: plasma. In a plasma, the atoms are split into positively charged ions and negatively charged electrons that can move about freely. Today scientists can already generate waves within a plasma that can accelerate electrons to energies in the realm of billions of electronvolts. These processes take place in fractions of a second on the scale of millionths of a metre. Researchers on the DESY campus are attempting to understand these processes in detail and make them usable – a breakthrough that would trigger the development of a wealth of applications for the new plasma accelerators.

Picture: Heiner Müller-Elsner, © DESY

Picture: Heiner Müller-Elsner, © DESY

Jens Osterhoff and his team use the electron beam from the FLASH accelerator for experiments with plasma cells.

Jens Osterhoff slowly turns the Plexiglas block, which is one and a half centimetres thick, between his thumb and his forefinger. He has studied this object in detail for his doctoral thesis. “Inside it are two sapphire blocks,” he explains. “Between them is a channel filled with hydrogen gas, which is only 0.3 millimetres wide. This is where the plasma is generated.” There’s not much here to see, because the channel between the sapphires is not much wider than a human hair. But Osterhoff’s plasma cell can generate particle energies of one gigaelectronvolt, or a billion electronvolts. – This scene took place five years ago.

Today, Osterhoff heads a team of approximately 20 scientists and students at DESY. Meanwhile, plasma accelerators are rapidly becoming more and more sophisticated and are now setting records in the range of several gigaelectronvolts. “The much larger field strengths that can be generated in plasmas make it possible to reduce the lengths required for acceleration from kilometres to metres,” says Osterhoff. “For example, the accelerator of FLASH, which is almost 100 metres long, would correspond to a plasma cell with a length measured in centimetres.”

But this is still a long way off, and the big accelerator facilities of today cannot yet be replaced. For his research, Osterhoff too relies on the large FLASH accelerator at DESY, which drives one of the coveted X-ray free-electron lasers by generating an extremely fine beam of very tiny electron bunches. This beam is used by Osterhoff and his team in the FLASHForward project to accelerate electrons in a ten-centimetre-long plasma cell and examine the resulting processes in detail.

Artist's representation of plasma acceleration: A laser flash (red) generates plasma waves on which electrons are surfing.

The principle: If a driver – that is, either a high-energy particle beam or an intense laser flash – is shot into a plasma cell, electrons are catapulted out of the gas atoms and a plasma is created. Positively charged atomic nuclei remain behind, while the electrons form a kind of wake behind the driver and very powerful electric fields develop within this wake. Osterhoff and his team use this plasma wave as a particle accelerator. "The electrons are effectively surfing on the plasma wave, and this accelerates them," Osterhoff explains. Electron beams as drivers are especially interesting for particle physics applications in which electrons have to be accelerated to the highest possible energies as efficiently as possible. "We are still far from being able to use plasma accelerators to generate particle beams of the quality that is necessary for high-energy physics, but in 20 years the situation might look different," says Osterhoff.

In 2016, FLASHForward will really get going and use the FLASH beams for experiments. Until then, the scientists will be running preliminary tests, among others in cooperation with the US accelerator centre SLAC in California. In addition, groups from DESY and the University of Hamburg are working together towards a shared goal under the umbrella of LAOLA, the Laboratory for Laser- and beam-driven plasma Acceleration. "We want to make the plasma accelerator ready for application," says LAOLA spokesman Florian Grüner.

"Our goal is to build the first tabletop FEL – in other words, a free-electron laser in a compact laboratory format."

Florian Grüner, spokesman of the LAOLA group

"At the moment, we are doing fundamental research in order to generate stable and controllable electron beams of high quality," says Grüner. Such high-quality beams are required to, for example, operate the X-ray free-electron lasers of the future, whose dimensions will be in the range of metres rather than kilometres like present-day facilities. "LAOLA is the global leader on the road to free-electron lasers based on plasma accelerators," Grüner emphasises. "Our goal is to build the first tabletop FEL – in other words, a free-electron laser in a compact laboratory format. During the next four to five years, we want to demonstrate that such a device will function in principle. That would be a decisive breakthrough!"

At DESY, various facilities are available for the accelerator experts. Experiments with plasma waves are possible not only at FLASH but also at the photo injector test facility PITZ at the DESY site in Zeuthen and at REGAE, a facility that generates extremely short electron bunches. The value of this pioneering work lies in the tremendous application potential offered by X-ray free-electron lasers. They make it possible to identify the atomic structure of individual molecules or "film" chemical reactions in real time – capabilities that open up completely new vistas for structural biology, medicine, materials science and nanotechnology. Large facilities such as the three-kilometre-long European XFEL, which is currently being built in the Hamburg metropolitan region, are available for such research. However, they are so big, complex and expensive that they will remain bound to just a few locations throughout the world. "If we succeed in creating compact free-electron lasers in laboratory dimensions, this pioneering technology could have broad applications at universities, hospitals and industrial companies as well," says Grüner with enthusiasm. "All we need for that is a high-power laser as a driver, a plasma accelerator on a centimetre scale, an undulator – that is, an arrangement of magnets in which the accelerated electrons emit X-ray flashes – and the experimental setup with the sample."

Nonetheless, before this can be done, accelerator physicists still need to acquire a great deal of fundamental knowledge about the processes that take place within femtoseconds (the unimaginably short billionth part of one millionth of a second) in a plasma in which extremely strong forces are operating between particles and waves that are moving at almost the speed of light. This is no easy task, but the necessary expertise is available on the DESY campus in Hamburg, according to Ralph Aßmann, whose group is developing new accelerator technologies at DESY. "Here we have experts who are researching ultrafast processes, and we have specialists in high-performance lasers and focused electron beams who have decades of experience in accelerator construction," he says. "We pool these skills across institutes and scientific disciplines in order to make plasma accelerators usable for practical applications. It's true that so far people have repeatedly set new acceleration records with plasma cells, but we can neither control the processes precisely enough, nor can we steer them. In other words, we can't utilise them."

"We want the breakthrough – being able to control the acceleration in plasma with sufficient precision – to take place at DESY!"
Ralph Aßmann, accelerator expert at DESY

In addition to the existing research opportunities, Aßmann and his team are pinning their hopes on a new facility that is being specially built for accelerator research: SINBAD, an impressive-sounding acronym that stands for Short Innovative Bunches and Accelerators at DESY. "SINBAD will allow us to research future accelerator technologies and take them to the application stage," Aßmann explains. To create SINBAD, the tunnel of the old DORIS accelerator at DESY is being reused and equipped with new technology. Today, SINBAD is still in the planning phase, but teams from LAOLA are helping to work on it, and the construction of the facility will begin in 2016. The accelerator physicists have a clear goal. "We want the breakthrough – being able to control the acceleration in plasma with sufficient precision – to take place at DESY!" Aßmann says. He's referring not only to the development of practicable and compact particle accelerators that open up new areas of application in science, medicine and industry. "We also need a Plan B for the next generation of high-energy accelerators," emphasises Aßmann, who also worked on the development of the 27-kilometre-long LHC accelerator near Geneva. "In future, conventional accelerators will simply come up against very practical limits in terms of their size and feasibility."

A cast, not an original

Archaeologists at DESY discover spectacular forgery by chance

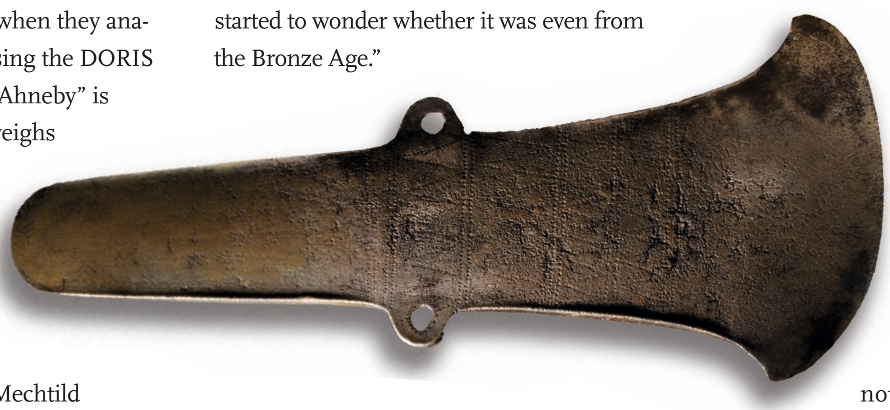
For a long time, several Bronze Age axes purportedly found in a damp meadow in the German state of Schleswig-Holstein in the 19th century were considered an archaeological treasure. Then, however, archaeologists examined one of the axes using the intense X-rays from a particle accelerator at DESY – and were shocked to discover that the axe in question was a fake, just like most of the other objects in the supposed find.

This incident shows how valuable physical measuring techniques can be for archaeologists, even though it means that the supposed value of a find drops rapidly if such a forgery is uncovered. The experts who discovered the forgery began working together a few years ago, when they analysed a Bronze Age axe using the DORIS storage ring. The "Axe of Ahneby" is around 4000 years old, weighs 700 grams and was likely a cult object in its time. "When we scanned the axe, we noticed that its surface had originally been littered with holes," says Mechtild Freudenberg from the State Archaeological Museum in Gottorf Castle. These holes likely formed during the bronze-casting process.

However, the Bronze Age craftsmen came up with a clever method for making the axe blade smooth nevertheless. "We discovered that the holes had been filled with pure tin," Freudenberg explains. "Apparently, the craftsmen corrected the problem by hammering tin beads into the holes."

The prehistoric patchwork wasn't revealed until the axe was scanned with high-intensity X-rays from DORIS.

Following this discovery, the team led by DESY physicist Leif Glaser decided to examine other axes using the non-destructive analytical method. The team was actually only interested in more closely studying the traces of work done on the blades. However, the scientists were taken aback when they discovered that the measured values for one of the tools deviated from the norm. "We then got suspicious after we used X-rays to analyse the chemical composition of the axe in question, which turned out to contain much too much iron and tin," says Freudenberg. "We therefore started to wonder whether it was even from the Bronze Age."



A true treasure: The "Axe of Ahneby" is really from the Bronze Age.

Picture: The State Archaeological Museum operated by the Schleswig-Holstein State Museum Foundation

Further analysis showed that the clearly visible imprints of hammer blows were merely superficial – and none of the changes to crystal structures typically caused by forging work could be found inside the material, either. "We didn't want to believe it at first, but the axe was clearly a cast replica – a fake!" says Freudenberg.

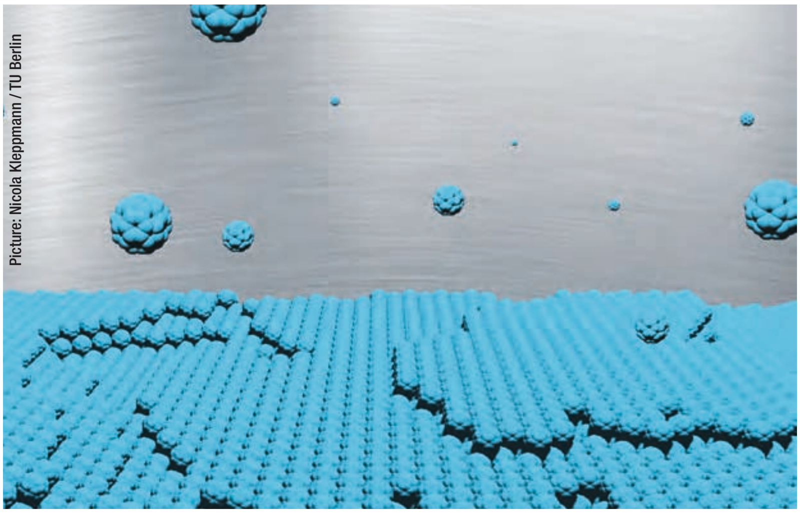
It wasn't a very pleasant surprise for the experts – after all, the axe had come from a supposedly reliable source. Johann Detlef Marxen, a well-respected private collector, had willed it to the Schleswig Museum back in 1864, together with 21 other objects that were supposedly found at the same Bronze Age site, which was a damp meadow near the town of Kappeln. Along with 15 axes, the excavation site also contained chisels and jewellery.

When the team scanned the other artefacts, they made a shocking discovery: everything, with the exception of a thin fibula (brooch) 25 centimetres long, was fake. Although it's no longer possible to determine who made those forgeries back in the 19th century, the measurements taken at DESY revealed that not all of the 21 fake objects were made at the same time, as they contain different alloys. "The forger evidently used whatever happened to be available," says Freudenberg. "We believe it was someone who worked in a metal foundry."

The archaeologists from Schleswig and the physicists in Hamburg plan to continue working together in the future in an interdisciplinary team that might discover other strange secrets from the past.

Live images from the nanocosmos

Researchers watch layers of football molecules grow



Artist's impression of the multilayer growth of buckyballs

Researchers at DESY have observed in real time how football-shaped carbon molecules arrange themselves into ultrasmooth layers. The scientists studied "buckyballs" – spherical molecules that consist of 60 carbon atoms (C_{60}). Because they are reminiscent of US architect Richard Buckminster Fuller's geodesic domes, they were christened "buckminsterfullerenes", or "buckyballs" for short. With their structure of alternating pentagons and hexagons, they also resemble tiny molecular footballs.

Together with theoretical simulations, the studies using DESY's PETRA III X-ray source are making it possible to understand for the first time how such molecular layers are formed. In the future, it will thus be possible to selectively grow nanostructures from these carbon molecules, which are playing an increasingly important role in the promising field of plastic electronics and can be used in handheld displays, for example. The research team consisted of scientists from Humboldt University in Berlin, the Technical University of Berlin, the University of Tübingen and DESY.

The X-ray source allowed the researchers to observe how buckyballs settle on a substrate from a molecular vapour. In fact, the carbon molecules grow layer by layer predominantly in islands that are only one molecule high, and barely form tower-like structures. "The first layer is 99 percent complete before 1 percent of the second layer is formed," explains DESY researcher Sebastian Bommel. This leads to the formation of extremely smooth layers.

"To really observe the growth process in real time, we needed to measure the surfaces on a molecular level faster than a single layer grows, which takes place over about a minute," says Stephan Roth, head of the P03 measuring station, where the experiments were carried out. "X-ray scattering investigations are well suited for this, as they can trace the growth process in detail."

"Our results provide fundamental insights into the molecular growth processes of a system that forms an important link between the world of atoms and that of colloids," says Nicola Kleppmann from the Technical University of Berlin. Through the combination of experimental observations and theoretical simulations, the scientists determined three major energy parameters simultaneously for such a system for the first time.

"With these values, we now really understand for the first time how such nanostructures grow," Bommel explains. "Using this knowledge, it is conceivable that these structures could be grown selectively in the future. For example, how must I change the temperature and deposition rate parameters so that an island of a particular size will grow? This could be interesting for organic solar cells that contain C_{60}." The researchers intend to explore the growth of other molecular systems in future using the same methods.

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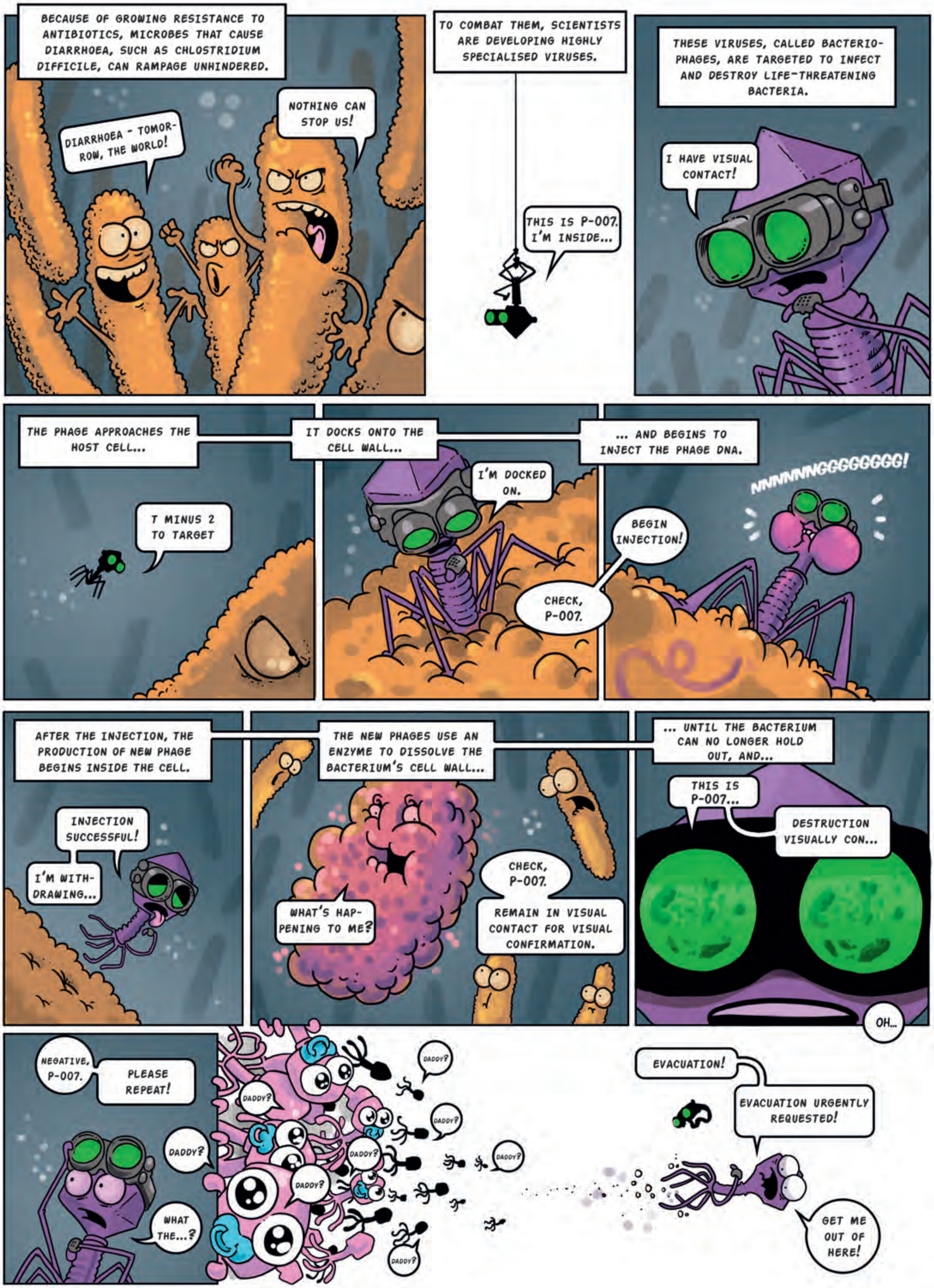
BECAUSE OF GROWING RESISTANCE TO ANTIBIOTICS, MICROBES THAT CAUSE DIARRHOEA, SUCH AS CHLOSTRIDIUM DIFFICILE, CAN RAMPAGE UNHINDERED.
DIARRHOEA - TOMORROW, THE WORLD!
NOTHING CAN STOP US!
TO COMBAT THEM, SCIENTISTS ARE DEVELOPING HIGHLY SPECIALISED VIRUSES.
THIS IS P-007. I'M INSIDE...
THESE VIRUSES, CALLED BACTERIOPHAGES, ARE TARGETED TO INFECT AND DESTROY LIFE-THREATENING BACTERIA.
I HAVE VISUAL CONTACT!
THE PHAGE APPROACHES THE HOST CELL...
T MINUS 2 TO TARGET
IT DOCKS ONTO THE CELL WALL...
I'M DOCKED ON.
... AND BEGINS TO INJECT THE PHAGE DNA.
NNNNNNNGGGGGGGG!
BEGIN INJECTION!
CHECK, P-007.
AFTER THE INJECTION, THE PRODUCTION OF NEW PHAGE BEGINS INSIDE THE CELL.
INJECTION SUCCESSFUL!
I'M WITHDRAWING...
THE NEW PHAGES USE AN ENZYME TO DISSOLVE THE BACTERIUM'S CELL WALL...
WHAT'S HAPPENING TO ME?
CHECK, P-007.
REMAIN IN VISUAL CONTACT FOR VISUAL CONFIRMATION.
... UNTIL THE BACTERIUM CAN NO LONGER HOLD OUT, AND...
THIS IS P-007...
DESTRUCTION VISUALLY CON...
OH...
NEGATIVE, P-007.
PLEASE REPEAT!
DADDY?
DADDY?
DADDY?
DADDY?
DADDY?
DADDY?
DADDY?
DADDY?
WHAT THE...?
EVACUATION!
EVACUATION URGENTLY REQUESTED!
GET ME OUT OF HERE!

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Curiosity is a strong incentive. It not only opens a door to the world for children, but also drives scientists to study and explain the universe with all of its components and the forces that prevail within it. Supersymmetry offers one theory that would solve many riddles. The building blocks of this new view of the universe are perhaps already within our reach – provided supersymmetry really exists.

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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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