DESY - opening new windows onto the universe

Unlocking the mysteries of the universe is all in a day's work for scientists at Deutsches Elektronen-Synchrotron (DESY) in Germany. Using the centre's powerful particle accelerators, they are able to probe into the secrets of exploding stars, black holes, the big bang and more. DESY's accelerators are also sources of intense electromagnetic radiation, which are used to perform pioneering investigations in the fields of physics, chemistry, geology, biology and medicine. We caught up with Professor **Dr. Helmut Dosch**, DESY's Chairman of the Board, to find out what makes DESY the world's leading centre for X-ray experiments.

Forget looking for a needle in a haystack, scientists at Deutsches Elektronen-Synchrotron (DESY) are looking for the tiniest building blocks of matter in the world. Based in Germany, DESY is an internationally leading accelerator centre, which houses the world's most intense X-ray source and particle accelerators that have achieved record speeds. These facilities enable the exploration of the microcosm, in all its infinite variety. Scientists can look at everything from the interactions of miniscule elementary particles and the behaviour of new types of nanomaterials, to biomolecular processes that are essential to life.

Solid-state physicist Professor Dr. Helmut Dosch is DESY's Chairman of the Board. He met up with *Research Features* to discuss some of the fascinating research that takes place at DESY and to outline some exciting future developments.

Firstly, can you explain what a particle accelerator does?

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

Can you tell me more about DESY's background and what the aims of the centre are?

DESY was founded in 1959 as a new lab in the north of Germany to operate a particle accelerator called an electron synchrotron. The great scientific success, the professional operation and subsequent international recognition of this facility led to a rather dynamic development becoming a leading centre for accelerator research and

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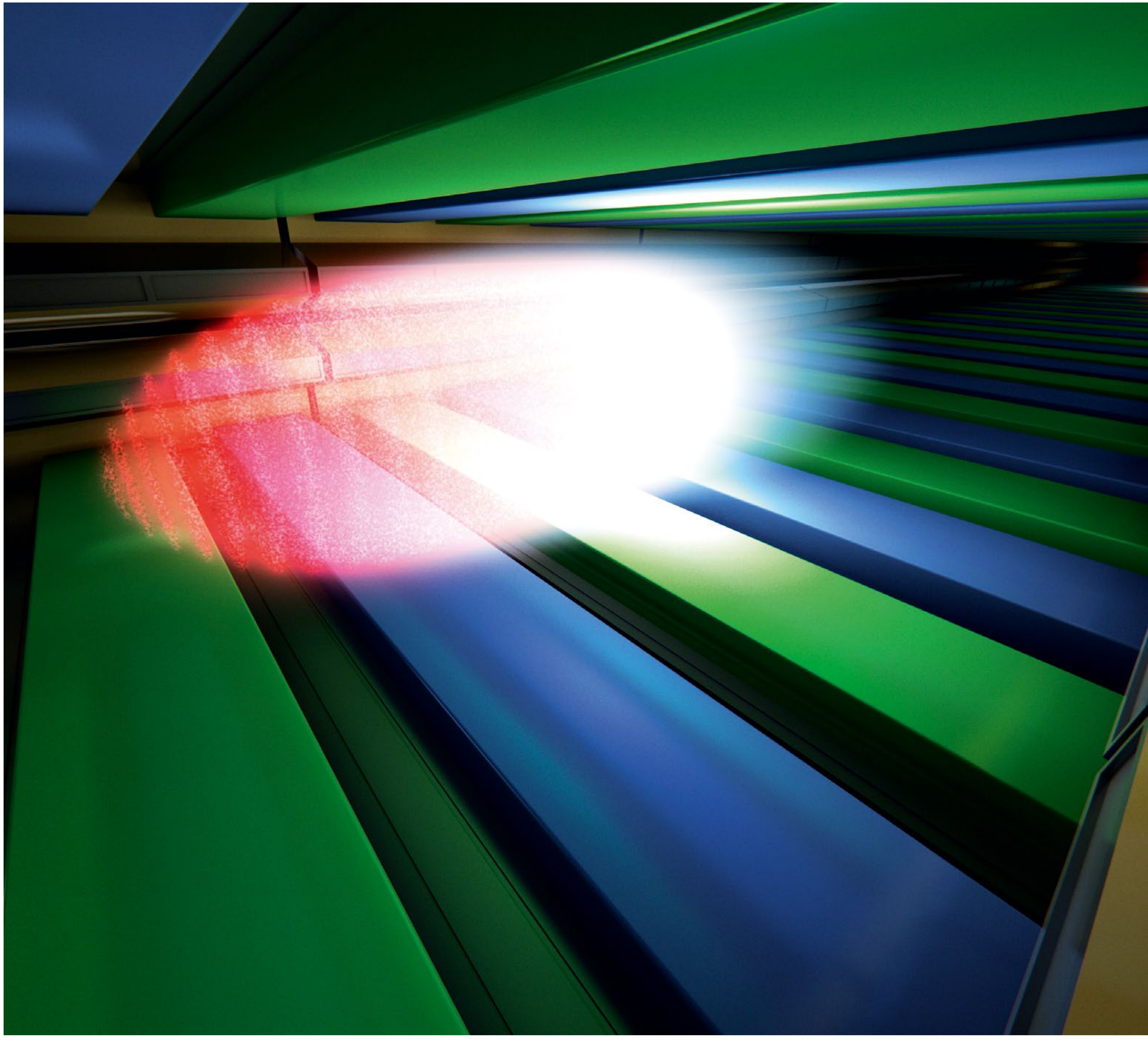

development (R&D) and particle physics. The particle physics legacy of DESY is intimately linked to the development of the storage rings (circular particle accelerators), DORIS, PETRA and HERA.

By the 1960s, the lab had pioneered the use of synchrotron radiation for the examination of matter, materials and biological systems. This quickly grew to a second branch of the lab: science with synchrotron radiation, plus X-ray lasers. This is today the main focus of DESY, which is now the site of the high brilliance storage ring PETRA III, the world´s first free-electron laser FLASH, and the European X-ray laser XFEL.

With the reunification of Germany in 1990, DESY once more expanded its size and its research portfolio. A new site was created at Zeuthen, near Berlin, in 1992, to explore astroparticle physics, and which is today on the verge of becoming an international centre in the field.

DESY's mission encompasses top level user operation of its X-ray facilities and research in photon science, nano-bio sciences, particle/astrophysics and accelerators R&D. We are creating the knowledge base that is needed in order to solve the huge and urgent challenges that society, science and the economy are facing. The research facilities we develop and operate for this purpose are open to scientists from all over the world.

DESY is member of the Helmholtz Association of German Research Centres.

How big an influence has DESY had on scientific research since it was established in 1959? What achievements really stand out for you?

DESY has always been a driver of new frontiers in science and technology. Among the many scientific achievements are the discovery of the gluon, the "glue particle" that holds the quarks together and without which there would be no atoms; the observation of B meson mixing; precise measurements of the structure of the proton; the discovery of the X-ray magnetic dichroism and of the synchrotron Moessbauer scattering. In collaboration with the Max Planck Society, ground-breaking work has been done to decipher the structure of ribosomes, the "protein factories" of living cells. For this, Ada Yonath, who conducted her research at DESY between 1984 and 2002, received the Nobel Prize in Chemistry in 2009. DESY has also been driving cutting edge science with free-electron lasers (FELs). Between 2000 and today, Henry Chapman at DESY pioneered serial femtocrystallography, which is widely considered to be the next quantum leap in structural biology.

DESY has had a seminal influence on the development of theory and of novel accelerator concepts. In 1987, Evgeny Saldin laid down the theoretical basis for free electron X-ray lasers. These devices can not only record the forms of atoms and molecules, but their functions too. At DESY, this revolutionary theoretical idea was first converted into X-ray laser facilities by developing superconducting accelerators which are today the heart of FLASH and the European XFEL.

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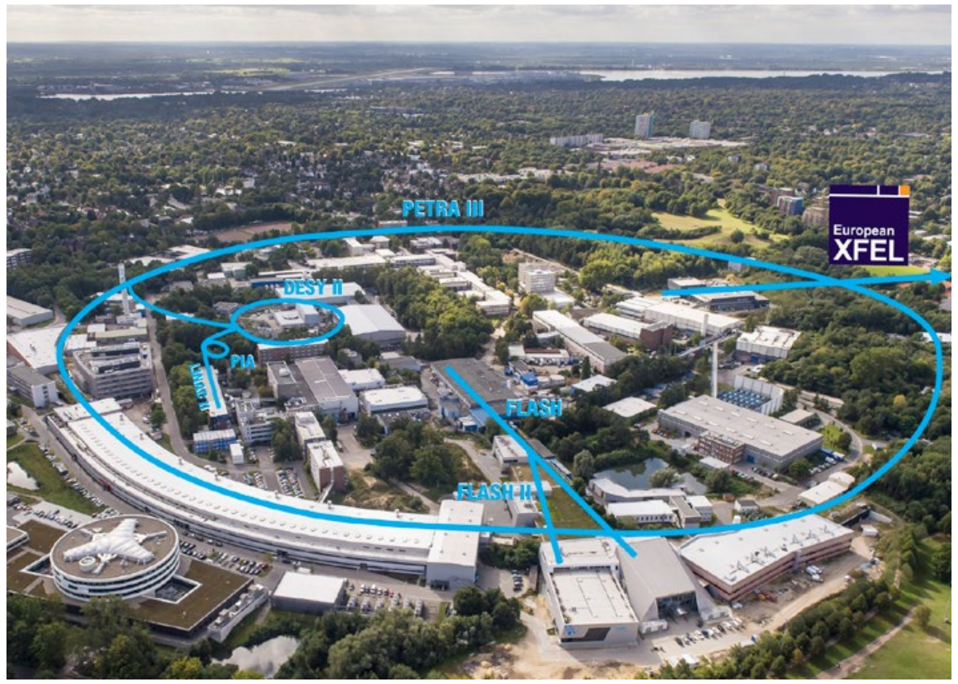

Particle accelerators at DESY (LINAC II, PIA and DESY II are preaccelerators for the operation of the storage ring PETRA III), together with the two free-electron lasers FLASH and the European XFEL

LEFT: The FLASH accelerator tunnel

Can you explain what photon science is? How did it become one of the main focuses of activity at DESY?

Photon science refers to all research disciplines which exploit the high brilliance X-ray radiation from electron accelerators. These "supermicroscopes" reveal the atomic details and the behaviour of materials and biomolecules – and form the basis for developing new technologies.

Examples of photon science include: protein crystallography, X-ray tomography of materials and angular resolved photoelectron spectroscopy of functional materials.

DESY pioneered this field in the 1960s, in parallel to its particle physics program. With the shut-down of DESY's last particle collider HERA, in 2007, and the parallel launch of the construction of the European XFEL, photon science became the main activity at DESY.

The European X-ray free electron laser (XFEL) is due to open at DESY later this year. Can you describe what it does and what its value will be to researchers? What is the significance for DESY of having this new research facility based on site?

The European XFEL is the most powerful X-ray source in the world. Its X-rays are used to study the nano world, as they are able to show much finer details than visible light. Their penetrating power allows access to the intrinsic time scale of the nanoworld, i.e. to the time scale of electronic and molecular motions. This enables researchers for the very first time to observe in real time how chemical bonds form and break, the holy grail in chemistry, catalysis and materials science. The European XFEL, and other similar facilities worldwide, will transform the way we design new materials and drugs.

DESY is the brain behind the European XFEL. DESY devised the idea, the concept and technical design and developed the accelerator technology, based on superconducting niobium. DESY is responsible for the heart of the XFEL, the 2km superconducting linear accelerator which brings electrons up to the energy of 17.5 GeV.

During the last few years, DESY has been building up interdisciplinary research labs on campus, such as the Center for Free Electron Laser Science (CFEL) and the Centre for Structural System Biology (CSSB), which will exploit the unique opportunities presented by the European XFEL. In the next few years, we will witness many disruptive scientific achievements in all areas of science. Clearly, the international reputation of DESY as a world-leading accelerator and photon science lab will further be boosted by the success of the European XFEL.

Can you tell us more about DESY's connection with the Large Hadron Collider (LHC) in Geneva?

After the shutdown of HERA in 2007, DESY very quickly developed a new enhanced cooperation with CERN. Today, most of the DESY activities in particle physics are focused on the LHC, and DESY is the national hub for the German LHC community. Currently, DESY is building up a detector assembly facility which will be used by all German universities for the construction of essential parts for the next generation of particle detectors at the LHC. At annual DESY-CERN board meetings, DESY synchronizes its particle physics priorities with the CERN directorate. There are also strong personal ties that connect DESY and CERN. For example, both the former Director General of CERN, Rolf Heuer, and the current Director for Research and Computing, Eckhart Elsen, spent a long time at DESY before their appointments at CERN.

Can you tell us about some of the exciting research projects currently taking place at DESY?

With pleasure, but this can only be a very personal selection and a snapshot of the many scientific breakthroughs coming out of the DESY labs and collaborations. I will highlight a few that show the breadth of science at DESY. Let's start with astrophysics. Various kinds of particles from the cosmos constantly reach the Earth – particles that can provide insights into the happenings in the depths of the universe. The DESY researchers in Zeuthen use two of these cosmic messengers, neutrinos and gamma rays, to uncover the secrets of stellar explosions, cosmic particle accelerators like the surroundings of black holes, or of dark matter.

As part of their studies, the researchers are involved in a collaborative project called IceCube, which operates a huge neutrino observatory below the surface of the Antarctic ice cap at the South Pole. Neutrinos hold the key to some of the most fundamental questions in physics, but they are notoriously difficult to study. However, their activities are easier to detect in deep ice. IceCube was built to search for high energy neutrinos created in the most extreme cosmic environments, a search that is driven by the wish to understand the origin and nature of cosmic rays. The IceCube observatory has already detected the highest energy neutrinos ever recorded.

Solid-state physicist Professor Dr Helmut Dosch is DESY's Chairman of the Board

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Now shift your focus from the South Pole to sub-Saharan Africa, where more than 60 million people are threatened by the sleeping sickness parasite, which is transmitted by the bite of the tsetse fly. Using serial femtocrystallography, a technique I mentioned earlier, DESY scientists and their collaborators exposed a possible Achilles' heel of this parasite. Their sophisticated analysis of data taken in experiments with a free-electron laser revealed the blueprint for a molecular plug that can selectively block a vital enzyme of the parasite, thereby rendering it inactive.

Another recent experiment at DESY's X-ray source PETRA III revealed, with atomic resolution, the structure of a key enzyme of the Zika virus. This enzyme is essentially the engine that enables the virus to replicate. If this enzyme could now be targeted with the right drug, thus inhibiting the replication, the infection could be stopped.

A more fundamental result was obtained at DESY's free-electron laser FLASH. Here, scientists found evidence of long elusive helium molecules consisting of three atoms (He3), whose existence was predicted 40 years ago by the Russian theoretical physicist Vitaly Efimov. This high-precision measurement of extremely weakly bound states illustrates the potential of FLASH. The discovery allows better understanding of metrology (measurement science) at low temperatures.

Last summer, we were given a glimpse of the future, with the first electron beam produced by an innovative accelerator project. This was a collaborative venture, conducted by DESY and the University of Hamburg. The technology used in the experiment, plasma-wakefield acceleration, will hopefully one day give rise to particle accelerators that are much smaller and more powerful than the ones we operate today. That is why a lot of effort and resources are devoted to this field of research. The electrons in this first test run were accelerated to energies of around 400 MeV, using a plasma cell of just a few millimetres in lengths. This corresponds very nearly to the energy that is achieved by DESY's linear pre-accelerator LINAC II – in 70 metres!

Finally, I would like to mention a more applied research project that has already sparked interest in the industry. It is about a new deposition method for custom-made magnetoresistive sensors, which will probably revolutionise the range of applications for magnetic sensors. These tiny, highly sensitive and efficient components are everywhere in our daily lives. In cars, they measure the speed of rotation of the wheels for ABS and ESP systems. They are also found in mobile phones, they read data from hard drives and contribute to our safety by detecting microscopic cracks in metal components. This variety of applications requires a very individual tailoring of these sensors for their respective functionality, a tuning that is extremely limited in conventional production methods. DESY scientists have now discovered a method that allows a plethora of new sensor properties to be achieved in a straightforward fashion. Instead of adjusting the application to fit the available sensors, the new technology means that one can customize the sensor to fit the intended application.

What are the key research focuses for the organisation over the next two years?

We will be working on the technical design reports for upgrades of PETRA III and for the free-electron laser FLASH, to ensure DESY's leading position in photon science in the future.

The start of the user operation of the European XFEL this summer is eagerly anticipated and we are looking forward to the first experiments there, for instance those at the Helmholtz International Beamline (HIB). HIB is a new kind of experimentation station, based at the XFEL, which will be used to conduct experiments under extreme conditions of high pressures, temperatures, or electromagnetic fields. The insights gleaned from these experiments will help improve models of planetary birth, among other things, and will also provide a basis for innovations in materials research and fusion technologies.

Researchers plan to use the "pump and probe" technique, where a dynamic process – for example, a chemical reaction – is started with one laser pulse and analysed with another laser pulse after a well-defined delay. Repeating the experiment with slowly increasing delay times provides a series of snapshots that can be arranged like a "molecular movie" flip-book of the reaction or process under investigation.

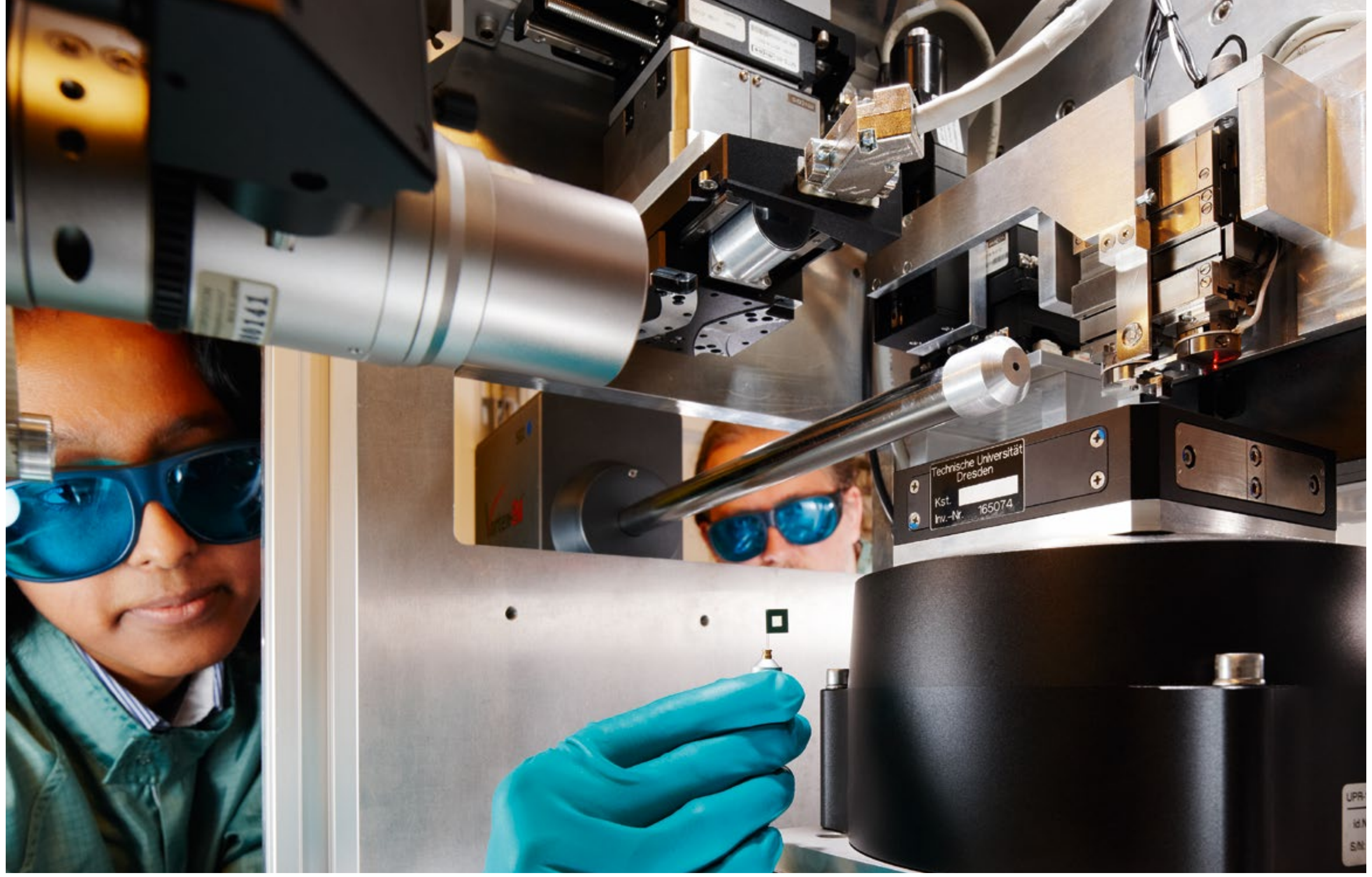
At the same time, there will be strong efforts to push the limits of accelerator technologies and establish a distributed test facility for laser-plasma acceleration. This technique could revolutionise not only the fields of photon science and particle physics, but also open the route towards innovative medical applications.

Last but not least, the Cherenkov Telescope Array (CTA) will be launched - the world's largest gamma-ray observatory and one of the cornerstones of astrophysics - at DESY in Zeuthen. Our researchers expect that observations made with the CTA observatory will unveil fascinating new phenomena and revolutionise our understanding of fundamental physical processes at the smallest and largest scales in our Universe.

International collaboration is a key element in DESY's success. What does DESY do to foster collaboration?

As you correctly say, international collaboration has always been and will in future remain a key for DESY's success. All DESY projects are so demanding that they require the collaboration of the best. In turn, DESY has always been striving to be a meeting and networking place for scientists from all over the world.

This implies an open mind and a culture of diversity, as well as professional structures for hosting scientists from abroad. These include an international office, a dual career centre, English as lingua franca, language and intercultural training courses, plus many other services. DESY´s research infrastructures play a central role, with robust funding which attracts young scientists and leaders in the field to Hamburg. DESY is a coveted partner for international cooperation. Its many strategic partnership agreements with leading research institutions across the world support long-term international cooperation projects.



Preparation of an experiment at the measuring station P06. The beamline P06 at the brillant X-ray source PETRA III provides advanced visualisation with micro/nanoscopic spatial resolution using different X-ray techniques

How do you see research at DESY changing over the next ten years?

I see several developments in the next years:

1. DESY will upgrade PETRA III into an ultimate storage ring providing coherent X-rays at 0.1 nm wavelength ("PETRA IV project"). This facility will allow novel X-ray imaging possibilities of all materials' properties, with the highest resolution, which will have a huge impact on the design of advanced materials.

2. DESY´s national and international role in astroparticle physics will strongly increase with the advent of the Cherenkov Telescope Array. DESY will host the CTA International Science and Data Management Center at its site in Zeuthen.

3. The DESY site in Hamburg is on its way to becoming an International Science Park, with new physics, chemistry and biology labs of the University of Hamburg to be built on campus. This will further boost the interdisciplinary use of DESY's facilities and attract more young scientists.

4. DESY will become more visibly engaged in the innovation chain and engage in strategic cooperation with industry.

5. DESY accelerator research will develop a strong focus in plasma acceleration technologies, with the aim to prepare a conceptual design report for a new facility fuelled by a plasma accelerator.

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