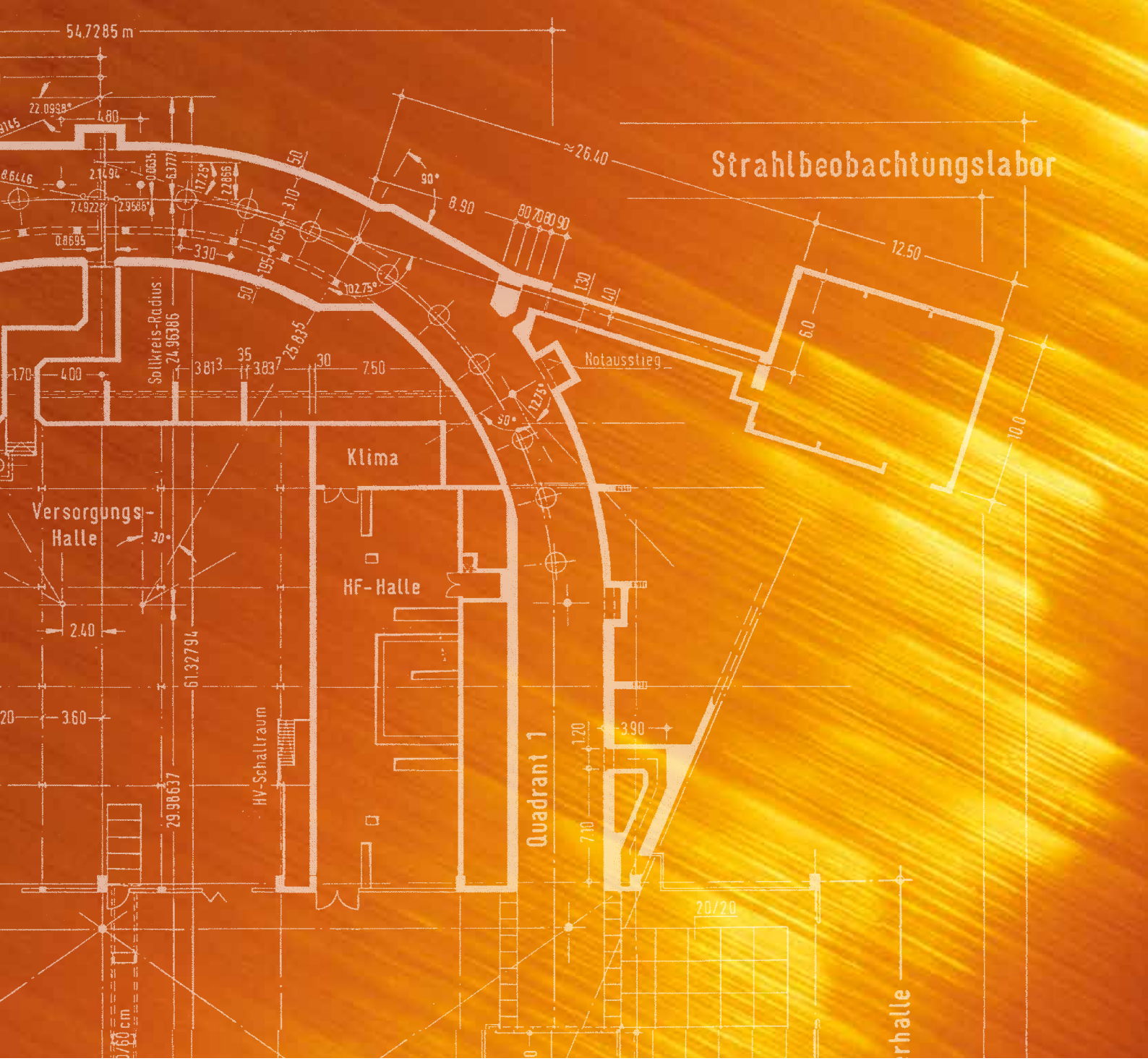


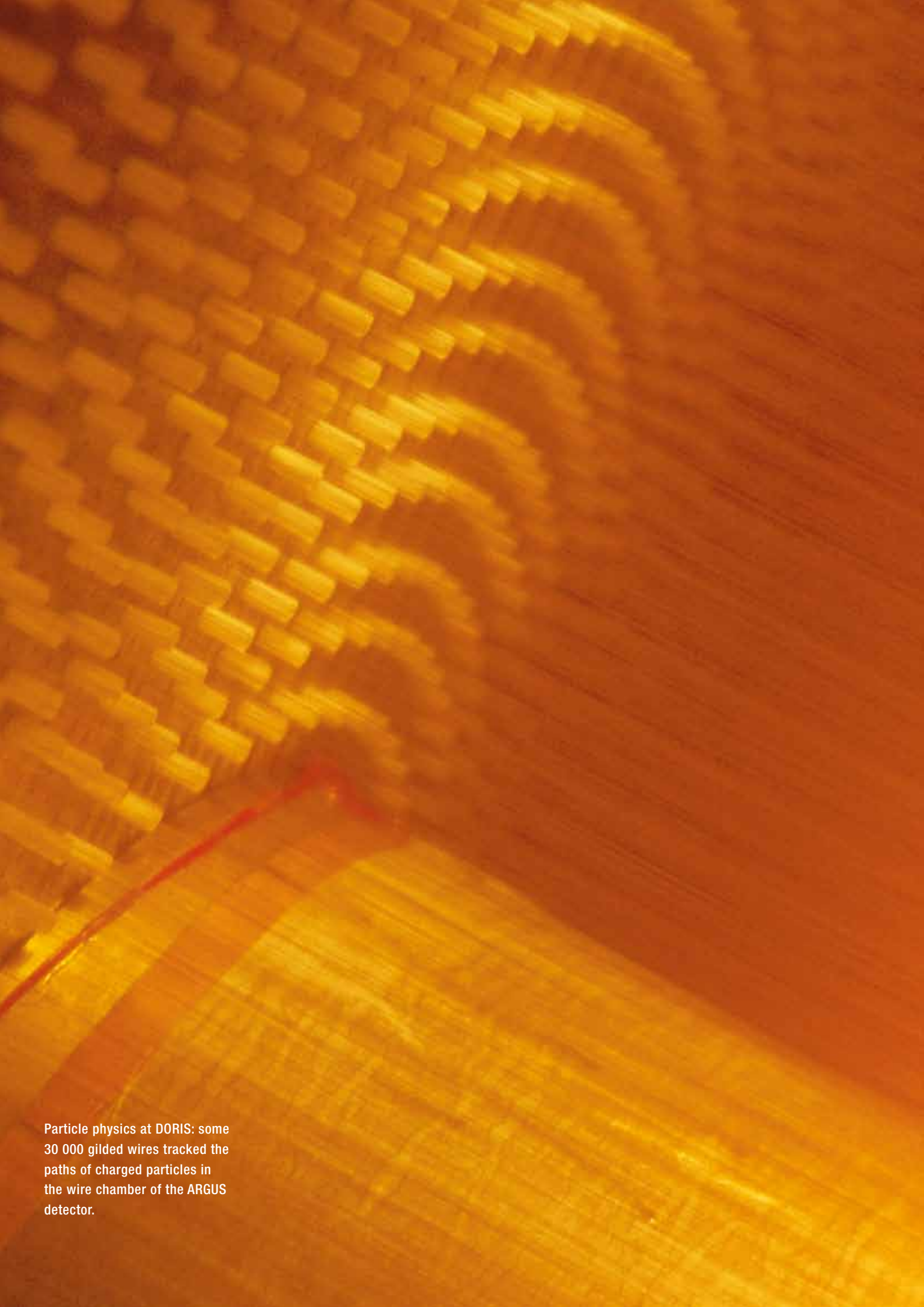
DORIS.

A particle accelerator makes scientific history

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

DESY



Particle physics at DORIS: some 30 000 gilded wires tracked the paths of charged particles in the wire chamber of the ARGUS detector.

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DORIS

DOPPEL-RING-SPEICHER

Technische Daten:

Teilchenart: Elektron-Positron ($e^- - e^+$), Elektron-Elektron ($e^- - e^-$)
Elektron-Proton ($e^- - p$)
Höchste Energie: 2 × 3,5 GeV, mittlerer Strom: 2 × 0,9 A bei 3 GeV
Abmessungen: 55 m × 110 m
Einschußsystem: Synchrotron, 2 GeV

DORIS

A particle accelerator makes scientific history

The success story of DORIS began almost 40 years ago. Since then, it has generated a tremendous variety of scientific findings and applications. DESY switched off this storage ring in early 2013, but the “DORIS era” is still shaping current research. Generations of researchers have used DORIS to develop and test numerous experimental methods, innovations, and technologies that have subsequently been applied in science and industry all over the world. Very few major research facilities in the world can look back on such a long and successful career in the world of science.

In 1968 a decision was made at DESY to build the first storage ring in Germany – a machine named DORIS. This was a bold decision, because at that time no one could say with certainty whether the new particle accelerator would deliver the desired results. But this boldness was rewarded. The machine initially delivered important results for particle physics, and later on it became an extremely successful and powerful source of synchrotron radiation.

DORIS was designed for the field of particle physics, and here the accelerator provided a large number of interesting results. That’s because the start-up of DORIS in 1974 occurred during a period of revolutionary change due to the surprising discovery of new quarks. DORIS made important contributions to this revolution in physics. Later on, after the larger PETRA storage ring had been commissioned in Hamburg, DORIS proved that even a small facility can deliver big results. For example, the researchers at DORIS used the ARGUS detector to discover an unusual interaction between matter and antimatter – and marked the start of a new era of particle physics.

The applications of synchrotron radiation, which was originally a by-product of the accelerator’s operation, turned out to be equally impressive. From the very beginning, researchers at DORIS made use of the intensely collimated X-ray radiation generated by the accelerator. Interest in this X-ray radiation quickly grew. As a result, the Hamburg Synchrotron Radiation Laboratory HASYLAB was opened in 1981, and it soon became an internationally renowned facility. Some years saw more than 2,000 experts from all over the world coming to Hamburg in order to run experiments at DORIS – physicists, chemists, and materials researchers, as well as biologists, geoscientists and engineers from industry. Hundreds of postgraduate and postdoctoral researchers earned their initial spurs as scientists at DORIS. Countless scientific cooperations arose between multinational, and sometimes interdisciplinary, teams to carry out joint experiments in Hamburg.

DORIS very impressively proves that when a major scientific facility is continuously adjusted to meet the requirements of science, it can be used sustainably over many decades. The people who constructed DORIS could not have begun to imagine the tremendous variety of cutting-edge results this particle accelerator would deliver in the course of time.

1969: construction of the DORIS storage ring begins

Four decades of excellence in research

The DORIS success story: from charm quarks to biomolecules

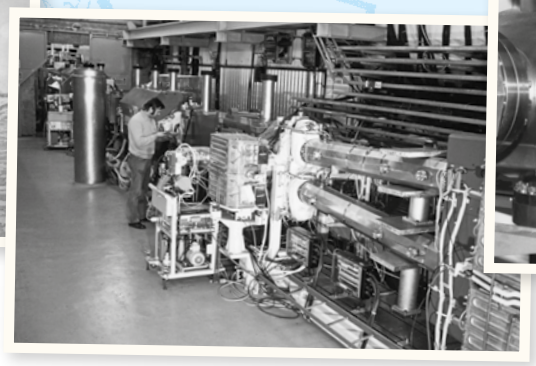
It was a pioneer – the first accelerator of its kind in Germany. When the DORIS storage ring started up in 1974, it was used mainly as a particle physics research tool. Later it became an indispensable source of X-rays that could be used in diverse scientific disciplines. The 300-metre ring was modernized three times and adapted to researchers' requirements. Its use over the years has generated a huge amount of fundamental and practical scientific knowledge.

The story of DORIS began in the mid-1960s, when DESY was still in its infancy. DESY, short for Deutsches Elektronen-Synchrotron (German Electron Synchrotron) was founded in 1959 as a research centre dedicated to a vital new field of physics: the study of the smallest fundamental particles of matter. DESY's first particle accelerator began operating on the centre's campus in Hamburg in 1964. This synchrotron, as it was called, was a ring with a circumference of 300 metres. At the time, DESY experts were fully occupied with the task of improving the machine's operation and conducting initial experiments. A small team of physicists was also assigned the task of planning DESY's future.

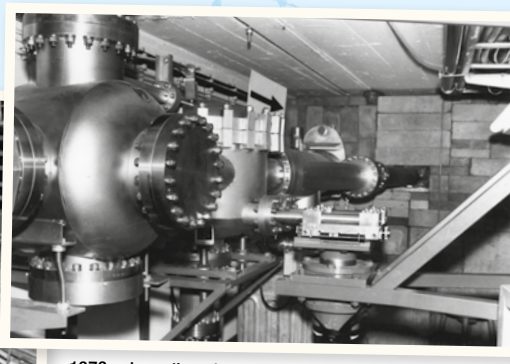
The ideas these scientists presented in 1966 sounded extremely visionary. For one thing, they recommended that DESY should take the risk of building a new type of accelerator known as a storage ring. This plan was controversial, since many experts were more interested in the logical idea of continuing DESY's original mission by constructing a second, more powerful, synchrotron that would produce a higher energy.

A synchrotron accelerates tiny particles such as electrons in a vacuum pipe to nearly the speed of light and then fires them onto a solid "target". This was the established method at the time for examining the building blocks of matter.

1968: pioneers of synchrotron radiation at DESY



1974: the DORIS storage ring



1976: a beamline at DORIS

The storage ring, on the other hand, was a novel and quite daring idea in 1966. Unlike a synchrotron, such a ring would accelerate and store the particles circling in the vacuum pipe for several hours. The electrons would be accelerated in clockwise direction around the ring, while their antiparticles (positrons) would circle in the opposite direction. This would make it possible to collide the two types of particles head-on at high energies, rather than colliding them with a solid target, as was the case with the synchrotron. This would result in a significantly higher collision energy and thus an unprecedented insight into the structure of matter.

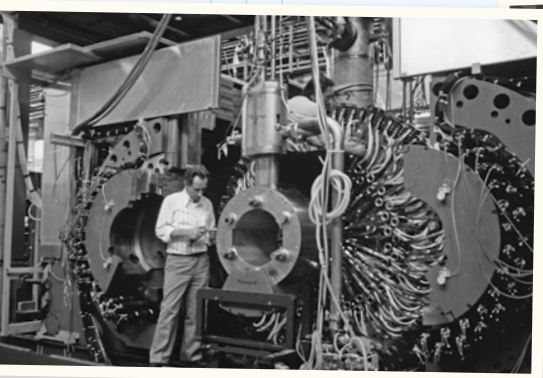
The problem was that the technology was still relatively new and had hardly been tested. Storage rings only existed as small prototypes at the time; the first electron-positron storage ring having been built in Italy in 1962 It had a circumference of just a few metres, making it little more than a sophisticated toy. Plans to build a 300-metre ring were therefore considered extremely daring.

No one knew if such a machine would actually produce anything interesting, so physicists were divided on the issue of whether it should be built. Some believed this type of innovative accelerator might offer opportunities to advance particle physics research, while others claimed that a storage ring made no sense and that its development should therefore be abandoned.

Nevertheless, those responsible for making the decision chose to take the risk – more from a gut feeling than because of any logical argument. Their daring ultimately paid off, as the use of storage rings for a broad range of applications increased over the years. The world's most powerful accelerator to date – the LHC in Geneva – is also a storage ring.

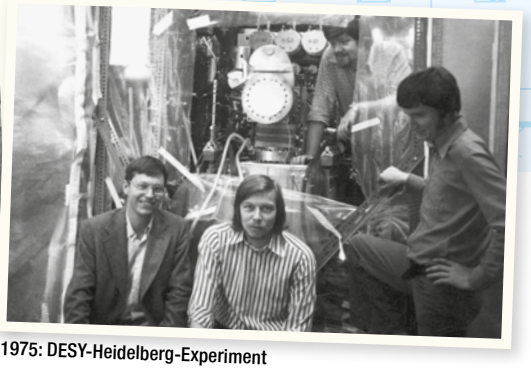
Another issue the experts discussed was the collision energy to which the new ring should accelerate the particles. Some thought four gigaelectronvolts (GeV) would be more than enough, especially since data would be very difficult to obtain in a storage ring that produced a higher energy. However, the DESY specialists, led by their director at the time, Willibald Jentschke, designed a machine that would reach six GeV, with the potential for expansion to nearly nine GeV. This decision would later prove to be correct.

Construction of DORIS (Double-Ring Store) began in 1969. The unit resembled a race track, as it had two curved segments linked by two straight sections, and a circumference of 288 metres. The original concept called for two vacuum pipes arranged on top of one another – one for the



1975: the PLUTO experiment

The DASP team



1975: DESY-Heidelberg-Experiment

electrons, the other for positrons that were to be accelerated in the opposite direction. That's why it was called a "double ring." Competing accelerators in the USA were pursuing a different approach with a single ring in which electrons and positrons circled in opposite directions, but the scientists in Germany wanted to retain the option of using DORIS to fire electrons at one another, which would only be possible with two separate pipes.

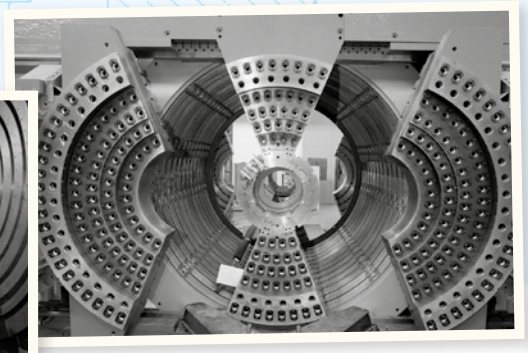
During the planning stage for DORIS, another group of researchers – scientists who worked with synchrotron radiation – also made a suggestion regarding the new storage ring's design. Synchrotron radiation is very intense and collimated X-ray radiation that accelerators generate as a kind of by-product. It can be used to look inside all sorts of materials with great effectiveness and much more precision than conventional X-rays, like those in doctors' practices, can offer. The initial synchrotron at DESY was already equipped with several measuring stations for studying the internal makeup of metals, semiconductors, and even insects' flight muscles.

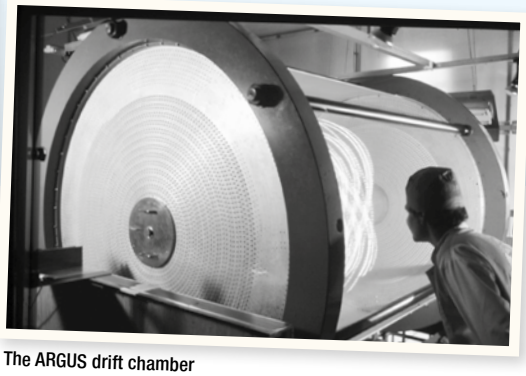
A storage ring like DORIS would enable the generation of a more stable X-ray beam that would also be one hundred times stronger than the radiation produced by the existing synchrotron. This is what made the idea so appealing. However, the technological possibilities were still limited at that time, so only a relatively small X-ray beam experiment lab was built. It was called Bunker 3, and its area of 120 square metres made it only slightly larger than a three-bedroom flat.

DORIS began operating in 1974 with two detectors, PLUTO and DASP, which were used to monitor particle collisions. Two similar accelerators had gone online in the USA shortly before DORIS, and experiments conducted with them in November 1974 (just prior to DORIS' initial measurements) led to the spectacular discovery of a new type of elementary particle known as the charm quark. Physicists referred to this feat as the "November Revolution", and scientists in Hamburg soon began studying the new quark, uncovering some important details on their own in the process.

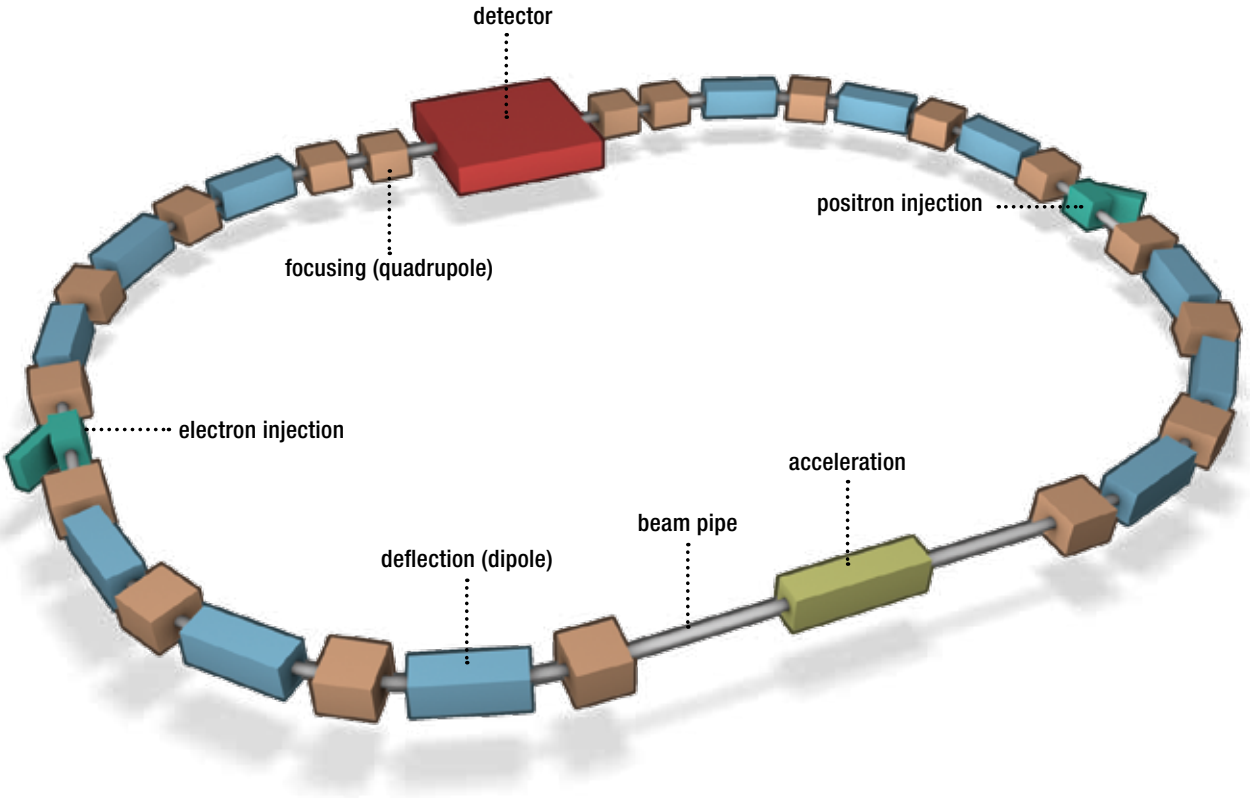
Synchrotron beam experiments began in 1974 at DORIS as well – with 40 users. One year later, a new lab building (Bunker 4) was completed at the storage ring site for the European Molecular Biology Laboratory (EMBL). This lab allowed scientists to closely examine biomolecules using X-rays. This EMBL outstation eventually became one of the world's most widely used synchrotron radiation biology labs.

1980: construction of the ARGUS detector





The ARGUS drift chamber

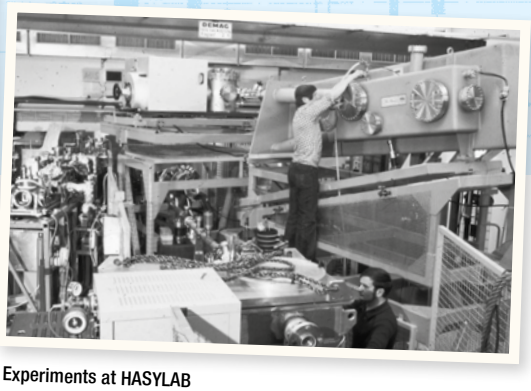


Storage ring

A storage ring accelerates particles such as electrons to nearly the speed of light, making them travel for hours on a circular path in a vacuum pipe. Other particles, usually positrons (the electrons' antiparticles), are fired in the opposite direction. The two types of particles are brought to a head-on collision in certain areas in the ring. The electrons and positrons then annihilate one another in a tiny but extremely dense energy flash – a ball of energy in which new particles – for example, heavy quarks – can form. Giant detectors, cameras for particles, monitor the collisions, and the measurement data they produce can be used by researchers to reconstruct the process and determine which new particles have formed in the accelerator.

The EMBL bunker at DORIS

Construction of the HASYLAB experimental hall



Experiments at HASYLAB

In 1977 scientists in the USA discovered another elementary particle – the fifth quark, which they later christened the “bottom quark” (b quark). The detailed analysis of this quark was expected to produce a wealth of new knowledge, but there was one problem: the energy that DORIS used at that time to accelerate particles and cause them to collide was not sufficient to produce the new quark. DESY officials therefore decided to upgrade the ring.

They installed additional acceleration sections and increased the power of the ring’s magnets. They also abandoned the double ring principle because it would have led to more drawbacks than benefits in the upgraded facility. From then on, DORIS accelerated particles in a single circular vacuum pipe. In early 1978, researchers at DORIS began conducting detailed studies of b quarks with the ring’s two detectors. Their experiments produced important findings for the Standard Model of particle physics, which was still new at that time.

Soon afterwards, the next DESY accelerator went into operation – PETRA, whose circumference of 2.3 kilometres made it much larger than DORIS. Its bigger dimensions enabled it to achieve the higher collision energy necessary for the discovery of new elementary particles. However, DORIS remained an important facility for researchers, particularly those interested in precise analyses of B mesons, special short-lived particles that contain a b quark. Such studies once again necessitated a facility upgrade, and that is why DORIS became DORIS II.

Machine physics experts re-equipped the magnets and increased the energy from nine to over 11 GeV in 1981. They also cut the ring’s electricity consumption in half. This was important, given the pressure to conserve energy after the oil crises of the 1970s. An international research team built the new ARGUS detector to monitor particle collisions at DORIS II. ARGUS began operating in 1982 and eventually became one of the most successful particle physics projects in DESY history.

The second group of researchers – those interested in synchrotron radiation – had gained a lot of influence in the years leading up to ARGUS. Their numbers had continually increased after DORIS was launched, and they had also developed new methods for using the collimated X-ray beams from the storage ring to examine various materials in precise detail.

1991: deflecting magnets in the DORIS accelerator

Nobel laureate Ada Yonath

Fuel cell under synchrotron radiation

In order to better organise such research at DORIS, a special lab was opened in 1981. Known as HASYLAB, it put the use of synchrotron radiation on an equal footing with particle physics experiments at DESY. HASYLAB became one of the incubators of successful research with synchrotron radiation worldwide.

Particle physicists and HASYLAB researchers shared the storage ring in the 1980s. During two thirds of the time allotted for data taking, DORIS operated in a mode optimized for the ARGUS detector. The X-ray beams could only be used "parasitically" during these intervals, so applications were restricted. One third of the time was reserved for HASYLAB experiments, with the ring adjusted to ensure it would generate as much radiation as possible. In this mode, DORIS II was the most brilliant source of X-rays in Europe – until 1994, when the European Synchrotron Radiation Facility (ESRF) began operating in Grenoble, France.

HASYLAB initially had 15 measuring stations, which were later increased to 30. Germany's Ministry of Research set up a special budget for synchrotron radiation in order to equip the stations with the proper instruments.

Funding from this budget has enabled universities in particular to install measuring stations in HASYLAB in line with the following principle: in the first year of operation, each group is given exclusive use of its measuring station in recognition of its commitment to the facility. After that, it has to allow other teams to reserve measuring time.

By 1986 the large HASYLAB experimental hall was completely full, with 30 measuring stations; additional labs were then added. The EMBL, for example, installed its own outstation at DESY in order to precisely analyze biomolecules. Molecular biologists from the Max Planck Society also set up permanent working groups. One of them was led by Ada Yonath, who conducted some of her most important experiments with DORIS and later received the Nobel Prize in Chemistry.

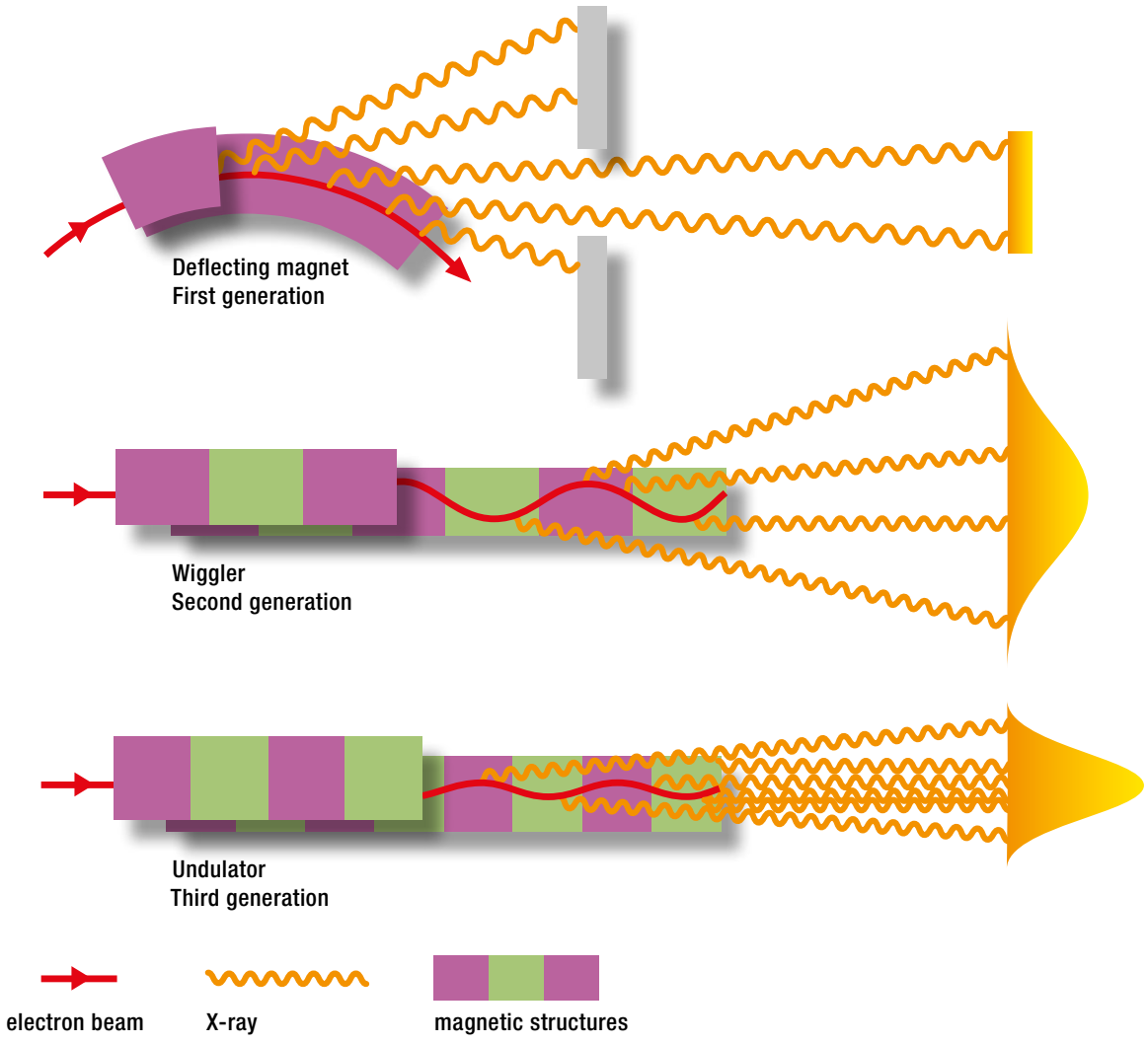
However, it soon became clear that the storage ring couldn't accommodate the many experts interested in using the intense X-ray light from DORIS. They included semiconductor physicists, materials researchers, chemists, geophysicists, biologists and medical engineers. Requests for experiment time came not only from Germany but also from renowned research institutes around the world.

The ARGUS detector as a welcoming exhibit near the DESY entrance

In the spotlight: measuring stations at HASYLAB

In 1986 researchers at HASYLAB proposed a further upgrade to the facility in order to accommodate the increasing demand. Their plan was to transform DORIS II into DORIS III by replacing one of the two straight sections with a 74-metre curved section that would be fitted with integrated special magnets known as wigglers and undulators. This would enable the number of measuring stations to be increased and also improve the quality and intensity of the X-ray beams. These special magnets would also make certain experiments possible for the first time.

Work began in 1990; DORIS III went on line one year later. The ARGUS particle detector was decommissioned in 1993 because conditions in the rebuilt ring inhibited the detector's ability to gather a sufficient amount of measurement data. Today the detector stands as an impressive exhibit at the entrance to DESY. Its spot in the DORIS storage ring was reoccupied in 2012, when an international research team began using the OLYMPUS detector to study certain properties of protons. Until that time, DORIS was available only to HASYLAB users. The bright X-ray source attracted up to 2,000 guest researchers from over 30 countries each year. These scientists used the collimated X-ray beams to analyze various material samples with approximately 80 measurement instruments. They ended up studying virtually all types of substances, including nanoparticles, semiconductor materials, plastics and even railway tracks, light bulbs and the paintings of the Old Masters. Medical engineers also developed a new X-ray technique for safely examining coronary vessels. This new method, which involved transporting patients through the collimated X-ray beam in a type of lift, was used to examine nearly 400 people.



Synchrotron radiation

Synchrotron radiation is produced when particles such as electrons circle inside an accelerator ring. When these electrons, which travel at nearly the speed of light, are guided into a curve by deflecting magnets, they emit a highly intense and collimated beam of light whose spectrum ranges from infrared light to X-rays. Magnets known as wigglers and undulators produce very powerful X-ray beams. These magnets consist of a sequence of alternating north and south poles that extends for several metres. The magnets force the electrons onto a slalom course that “elicits” a particularly intense beam from them. Synchrotron radiation is millions of times more brilliant than anything a physician’s X-ray machine can produce. Scientists use it to study the properties of various materials, including metals, semiconductors, and even plastics and protein molecules.

On 2 January 2013 the DORIS storage ring was switched off.

Disassembly of the DORIS experiments

The storage ring was finally shut down on 2 January 2013. The tremendous range of research opportunities DORIS offered made it a milestone for scientific research. Today DESY is one of the world's leading facilities for experiments with photons, for which it employs extremely powerful sources of light to study the structure of matter.

The FLASH free-electron laser and the PETRA III X-ray source now produce radiation that is more intense and collimated than the beams generated by DORIS. In a few years the European XFEL X-ray laser will begin producing the most powerful X-ray beams of all time. PETRA III is also being expanded and equipped with additional measuring stations. The precursors of some of these stations were already operating with DORIS and are thus the direct descendants of one of the most successful particle accelerators in the history of science.

Inter-cultural relations

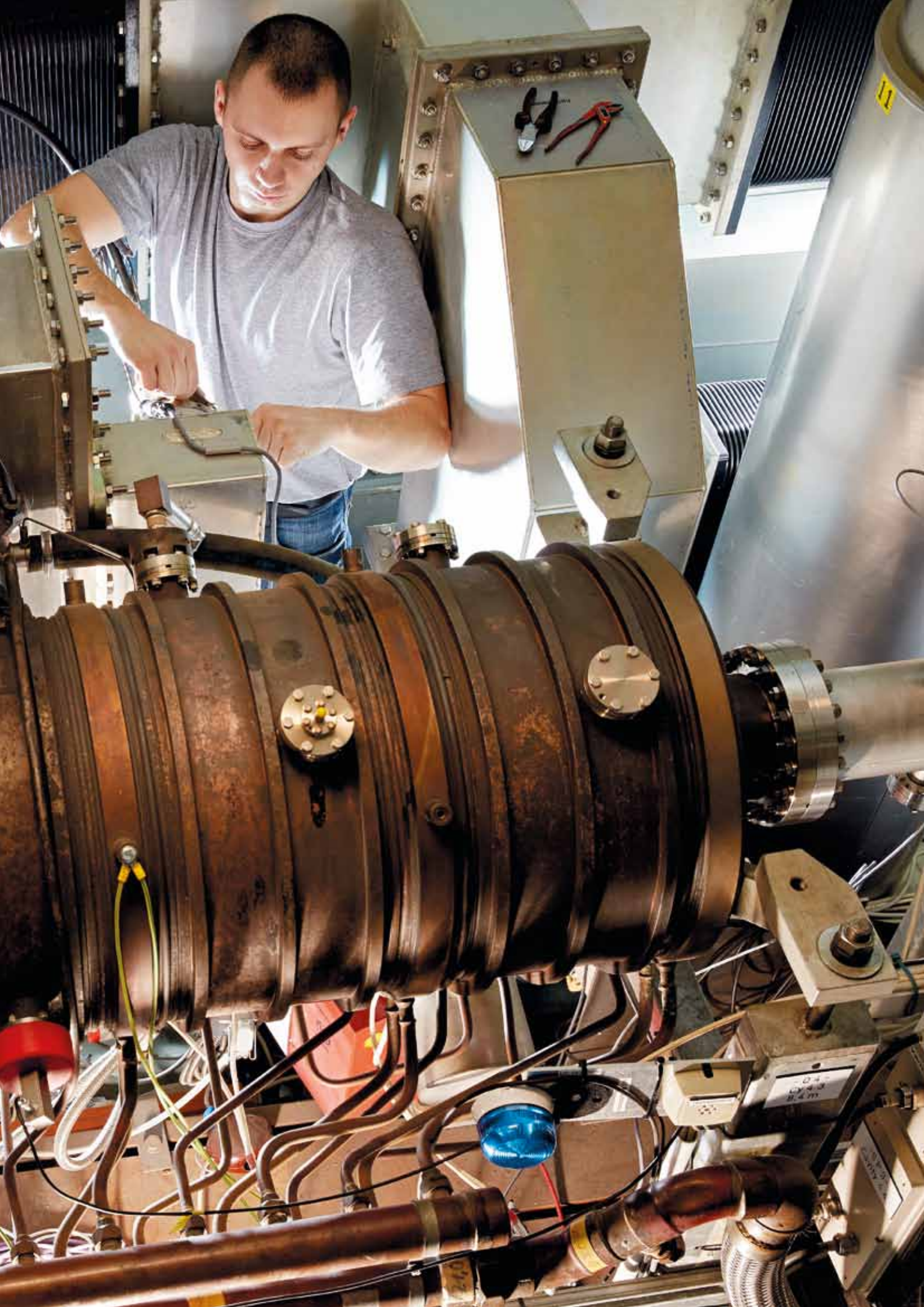
ARGUS – A Russian-German-United States-Swedish Collaboration

Particle physics means working inter-cultural relations. No detector has more proof of that than ARGUS. The shared curiosity for the physics brought physicists from the West and from Russia together – in spite of the Cold War they hunted together for clues of what holds the world together.

ACCELERATOR TECHNOLOGY

When DORIS went into operation in 1974, it was considered one of the most innovative facilities of its time. Many technical advances were used in its construction – some of which were extremely relevant for industry. And, each time DORIS underwent a significant modernization, the experts came up with more innovations – which often proved valuable for other research facilities as well.

Accelerator module made of copper



A space with no air

How new vacuum technologies were developed for DORIS

In order for a storage ring like DORIS to function at all, one thing is absolutely necessary: the ring pipe through which the high-speed particles travel must contain as perfect a vacuum as possible. Otherwise the speeding particles would constantly collide with air molecules and thus rapidly disappear. In order to create the best possible vacuum in the ring pipe, the pipe must be airtight and evacuated using special pumps. The technical challenge involved is enormous, as the pressure in the pipe must be about a trillion times lower than that of the outside atmosphere.

"A number of new developments were initiated for the DORIS vacuum system. Some of them were also relevant for industry."

Dr. Lutz Lilje, accelerator expert and head of the Vacuum Group at DESY

In order to achieve such low pressures for DORIS, experts at DESY had to create or develop new technologies in the 1970s. For example, copper components had to be bonded to structural elements made of steel. The pieces therefore had to be soldered together at a high temperature – with the disadvantage that the copper was left too weak for everyday operations. For this reason the DESY vacuum experts worked together with specialists from Norddeutsche Affinerie (today Aurubis), one of the world's leading copper producers. The results of this cooperation were special copper alloys that remained hard enough after soldering.

The experts also developed new types of silver-based solder. The advantage here is that some of the solder materials are more fluid then others at higher temperatures. That makes it possible to solder several components, one after the other, onto a structural element – an effective method that is still in use today. For example, this technique was used during construction of the European XFEL X-ray laser. In addition, an extrusion method was developed in collaboration with the Osnabrück-based company kabelmetal (today KME AG). This made it possible to form complex-shaped vacuum pipes virtually in one piece – a great simplification of the manufacturing process. Today extrusion plays an important role in the manufacture of complex aluminium profiles.

Finally, the vacuum experts explored the theoretical essentials of a special kind of pump, the ion getter pump. The principle is simple: residual gas particles are ionized and a high voltage deflects them to a surface, to which they adhere. The concept has been very successful. Today ion getter pumps are used in many areas of vacuum technology. Precise understanding also made it possible to build technically simpler designs. Thus it was possible to reduce the number of active ion getter pumps, and the entire vacuum system became more robust.

Many of the components in the DORIS accelerator tunnel had to be pumped free of air. This required some sophisticated technology.

Special sensors were integrated into the DORIS accelerator ring. They registered the particle bunches circling at nearly the speed of light through the vacuum pipe. Correcting magnets held the particles on course.

Shock absorbers for particle bunches

A new type of feedback control provides more measurement data

The more the better. This simple rule also applies to accelerators. After all, the more particles a storage ring can accelerate, the more data it can deliver. In particle physics, this leads to a larger number of collisions that can be analyzed. And during the generation of synchrotron radiation, the X-rays are significantly more intense when there are more particles racing around the ring.

However, it is not easy to pack a storage ring with more and more particles – with electrons, for example. This is because billions of electrons are packaged into match-sized bunches and these bunches have an electrical charge. As they pass through the vacuum pipe at nearly the speed of light they create high-frequency electric fields. The problem is that if too many electrons are forced into an electron bunch, these fields will have such a strong effect on it that it will begin to oscillate and ultimately fly apart – just as an inexperienced driver on a slalom course will begin to fishtail to such an extent that the car careens off course.

At the end of the 1980s DESY physicists came up with a new process to solve this problem: the multibunch feedback system. It starts with a row of sensors that measure how strongly the electron bunches flying by are already oscillating. Based on the data from the sensors, a computer works out highly precise signals in real time that it uses to control special correcting magnets. These magnets work in opposition to the self-reinforcing oscillations and act as a kind of intelligent shock absorber.

The particular challenge here is that ten electron bunches are orbiting inside the DORIS storage ring at any given time, and the feedback system has to be able to control all ten bunches separately. The system was developed at DESY. Together with PETRA, DORIS was the first storage ring where it was installed – with impressive results. Thanks to the new technology, it was possible to increase the number of particles per bunch by a factor of five. It's therefore no surprise that the system was subsequently also installed in many other electron storage rings. In 1996 the experts at DESY were awarded the prestigious prize of the European Physical Society for this development.

A sophisticated response to imbalances

DESY researchers developed an innovative control system

Prior to the early 1980s, the users of synchrotron radiation were faced with a problem that affected every facility in the world: the beam of X-rays they used to illuminate their samples behaved a bit like the light from a torch held in a shaking hand. It didn't stay focused on a single point but wandered around. It was a nuisance for the researchers, because the more steadily and evenly they can light their samples from the same direction, the better their measurement data is.

"The beam position control that we developed for DORIS all those years ago is a given at all of the synchrotron radiation sources around the world today."

Dr. Werner Brefeld, accelerator physicist at DESY

The reasons for the unsteady X-ray beam included fluctuations in temperature and vibrations in the accelerator tunnel. Both would disturb the magnets that keep the particles on course. These disturbances of the magnets inevitably had an effect on the particles' flight path. They would in effect get bumped out of their position and fly slightly higher or lower than expected. This caused changes in the direction of the beam of light being emitted by the particles travelling around the curve of the accelerator – in other words, the X-rays "wobbled".

In 1983, in order to mitigate the "wobble" problem DESY researchers developed a sophisticated correction technology: the Beam Position Control. Experts in the USA were also addressing the same issue. Basically, the system works like this: a variety of sensors observe the current positions of the particles in the ring, as well as the positions of the X-ray beams as they head towards the measuring stations. The values obtained by these sensors are fed to a computer. Here, software compares the respective actual values with the desired values – in other words, the values of the optimal positions and directions of the X-ray beams at the measuring stations. If the deviation between the actual values and the desired values is too great, the computer makes an adjustment and sends a correcting signal to some of the magnets in the accelerator.

With this method a potential particle imbalance can be smoothed out. The X-ray beam stays where it should be. DORIS is one of the first accelerators in the world for which this correction technology was developed. Today these kinds of beam position controls are standard and essential equipment in state-of-the-art X-ray sources such as PETRA III in Hamburg and the ESRF in Grenoble.

A slalom course generates bright light

The first multipole wiggler in Europe was installed at DORIS

Working in California, the German-born American physicist Klaus Halbach developed a new special magnet – the multipole wiggler consisting of permanent magnets – in 1980. His magnet would go on to revolutionize research with synchrotron radiation. It is made up of a precisely arranged row of small magnet blocks. This construction has a special effect on a high-speed electron beam: it causes the particles to travel along a “slalom” path. As a result, the electrons emit an X-ray beam that is up to a thousand times more powerful than the beams produced with the deflecting magnets previously used.

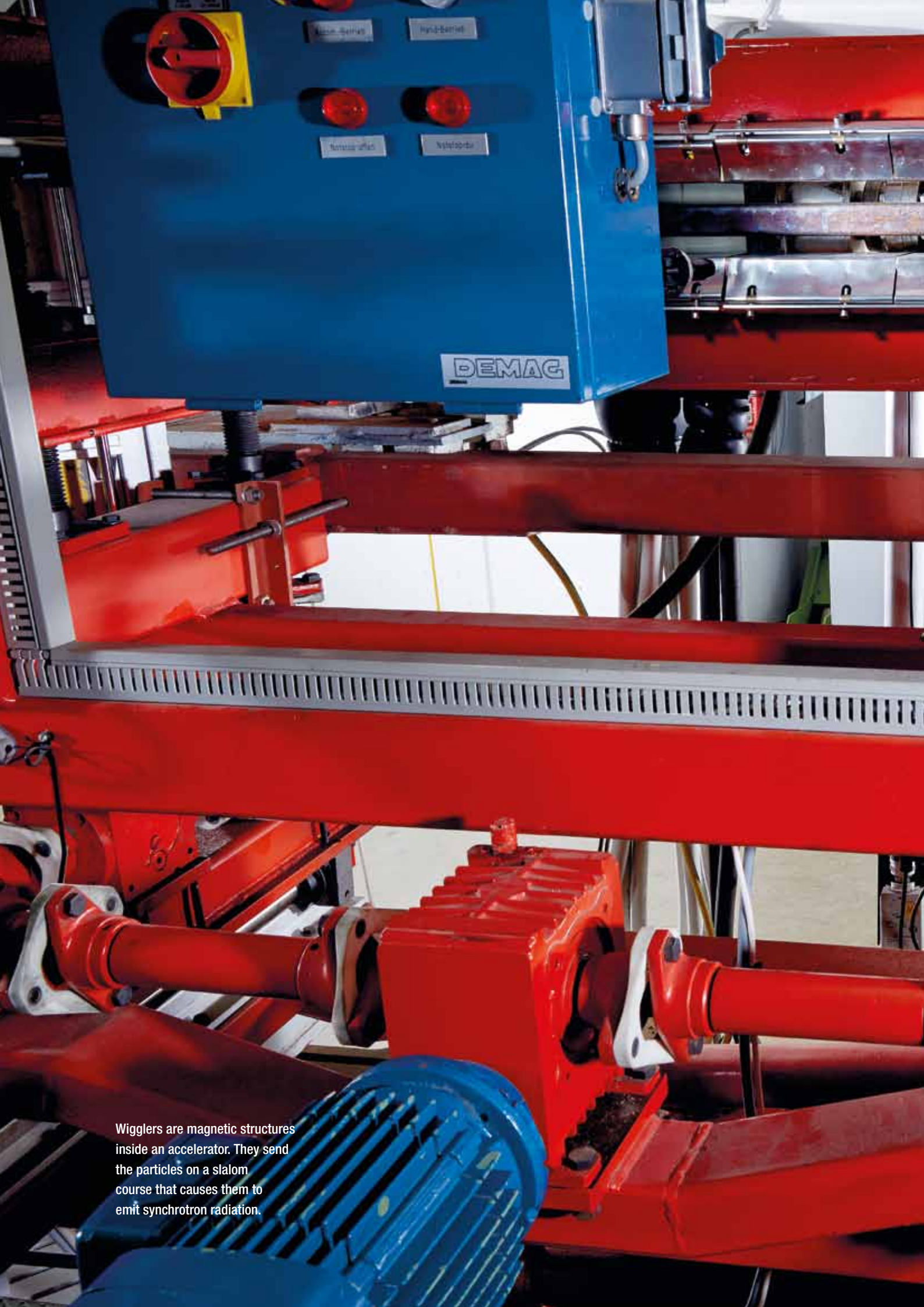
The DESY researchers quickly realized how valuable this special magnet would be for research and decided to install this type of multipole wiggler at DORIS as soon as possible. The facility would be the first of its kind in Europe. In order to learn more about the technology they invited Halbach to come to Hamburg. Although he did present the basic principles of his invention, he otherwise remained fairly tight-lipped about it. In fact, he kept the decisive details to himself.

As a result, the DESY experts had no alternative but to start from scratch and develop the magnet completely on their own. They had to write programs for the rather primitive computers of the time so that they could work out the specific X-ray spectra that the multipole wiggler should deliver. Another challenge was the precision with which the individual magnet blocks had to be joined together to form a complete structure.

In 1983 the first wiggler was finished and installed at DORIS. It worked immediately. Subsequent models followed and later the experts refined the concept and constructed undulators. At specific wavelengths these magnet structures create significantly more intense radiation than a wiggler. Altogether, ten wigglers and undulators have been in operation at DORIS since 1991. The newest generation of X-ray sources – free-electron lasers such as FLASH and the European XFEL – couldn’t generate X-rays without undulators.

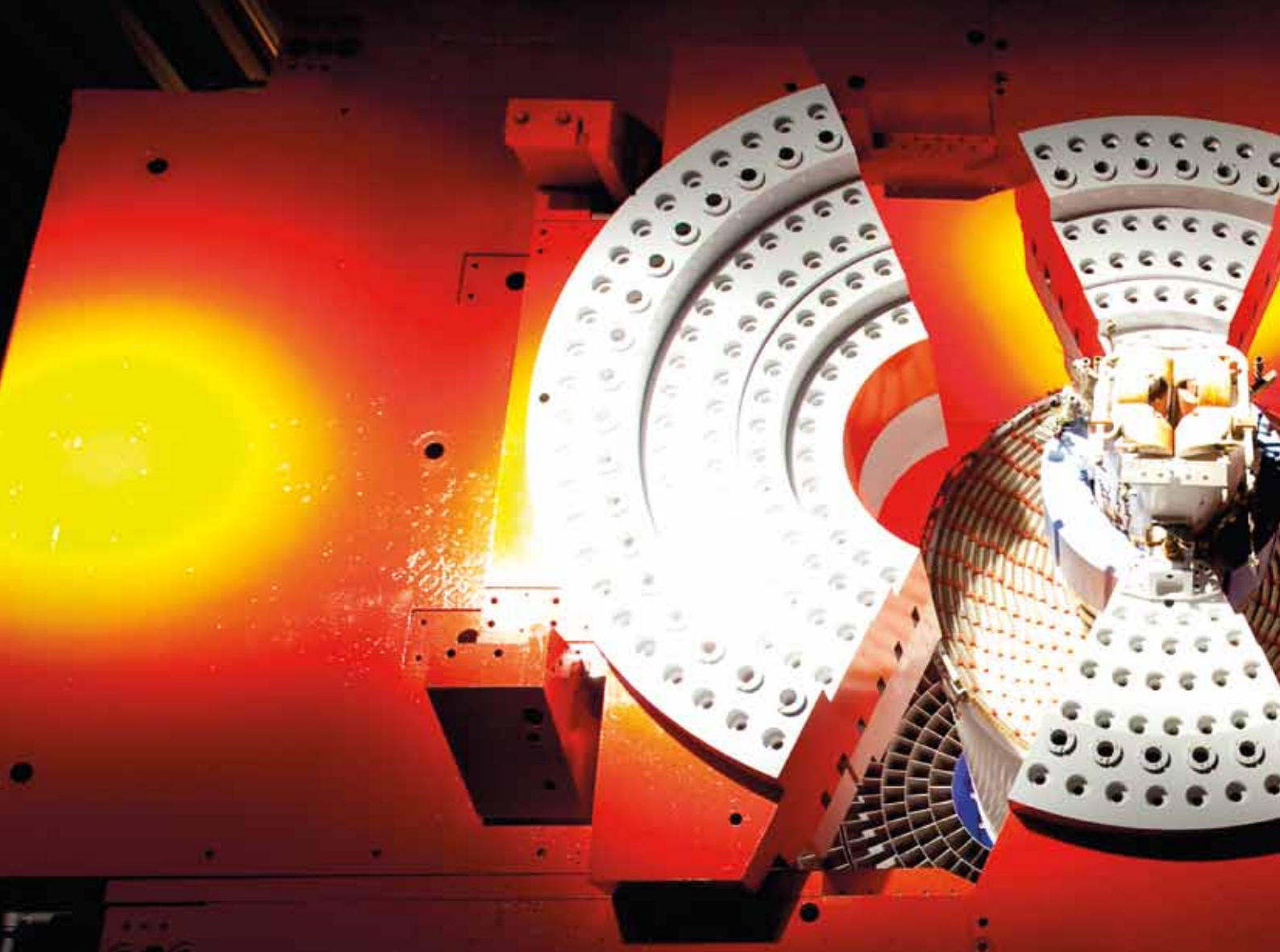
In 1989 a variation of this concept was developed at DORIS: the “asymmetrical” wiggler. In contrast to a normal wiggler, an asymmetrical wiggler’s north and south poles have different strengths. This difference makes it possible to create X-rays with “circular” polarization – radiation that oscillates in a specific direction and is particularly suited to detailed examination of magnetic materials. Previously it had only been possible to create radiation with circular polarization using deflection magnets. Asymmetrical wigglers deliver this radiation at a much higher intensity. Today they are in operation at a number of X-ray sources around the world, and a super-conducting version has also been developed.

The first wiggler magnet was completed at DESY in 1983 and inserted into DORIS (above). Modern wigglers have a significantly longer line of magnets.



Wigglers are magnetic structures inside an accelerator. They send the particles on a slalom course that causes them to emit synchrotron radiation.

DESY



PARTICLE PHYSICS

Particle physicists seek to discover the basic building blocks of matter and the natural forces that act between them. The foundation for particle physics research – the Standard Model – was developed and refined during the 1970s and 1980s. Experiments at the DORIS storage ring made a significant contribution to this picture of our world, which is still valid today.

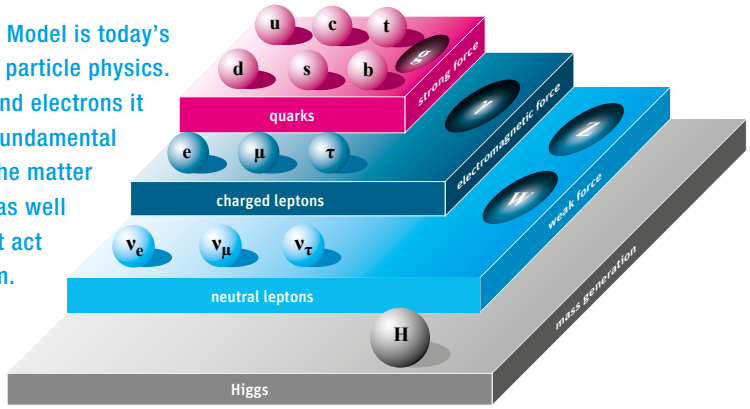
The ARGUS detector

On the way to the Standard Model

DORIS produced groundbreaking insights in the field of particle physics

Lots of things were happening in particle physics when DORIS began operating in 1974. Accelerators in the USA had recently identified a new particle consisting of “charm quarks.” The scientists who made this discovery were later awarded the Nobel Prize in Physics. Quarks are one of the building blocks of matter, and the charm quark was the fourth quark to be discovered of the six we know today.

The Standard Model is today’s theory of elementary particle physics. With quarks and electrons it describes the fundamental buildings blocks of the matter that surrounds us as well as the forces that act between them.



Physicists began to closely study the new particle’s properties after DORIS went into operation. And their efforts were successful: their detectors registered several “excited states” of the particle. A further game-changing discovery was made in 1977, when physicists in the USA observed the fifth quark, known today as the bottom or b quark. After DORIS was upgraded to provide more energy, scientists at the storage ring could also observe this quark, with interesting results. For example, researchers working with the PLUTO and DASP II detectors found that the electrical charge of the b quark is exactly one third of the electron charge.

PLUTO also played a major role in the discovery of the tau lepton, a heavier “brother” of the electron.

In addition, PLUTO and DASP II demonstrated that a specific particle consisting solely of b quarks can decay in a peculiar manner. This was the first indication of the existence of gluons – particles that hold quarks and thus all matter together. Firm proof of the existence of gluons was provided a short time later by another DESY accelerator: the PETRA storage ring. All these discoveries helped to firmly establish quark theory in physics, even among scientists who had previously been sceptical.

Innovative detector design

DORIS was the first facility to use a superconducting magnet to search for particles

PLUTO, one of the two detectors set up at DORIS when the storage ring went into operation in 1974, analysed exactly what occurred during the frontal collisions between fast-moving electrons and positrons. Such collisions can create new and exotic elementary particles, which immediately decay into other particles. Facilities such as PLUTO can detect these fragments with maximum precision. Physicists can use the resulting data to reconstruct the process involved and determine which exotic particles were created by the collisions.

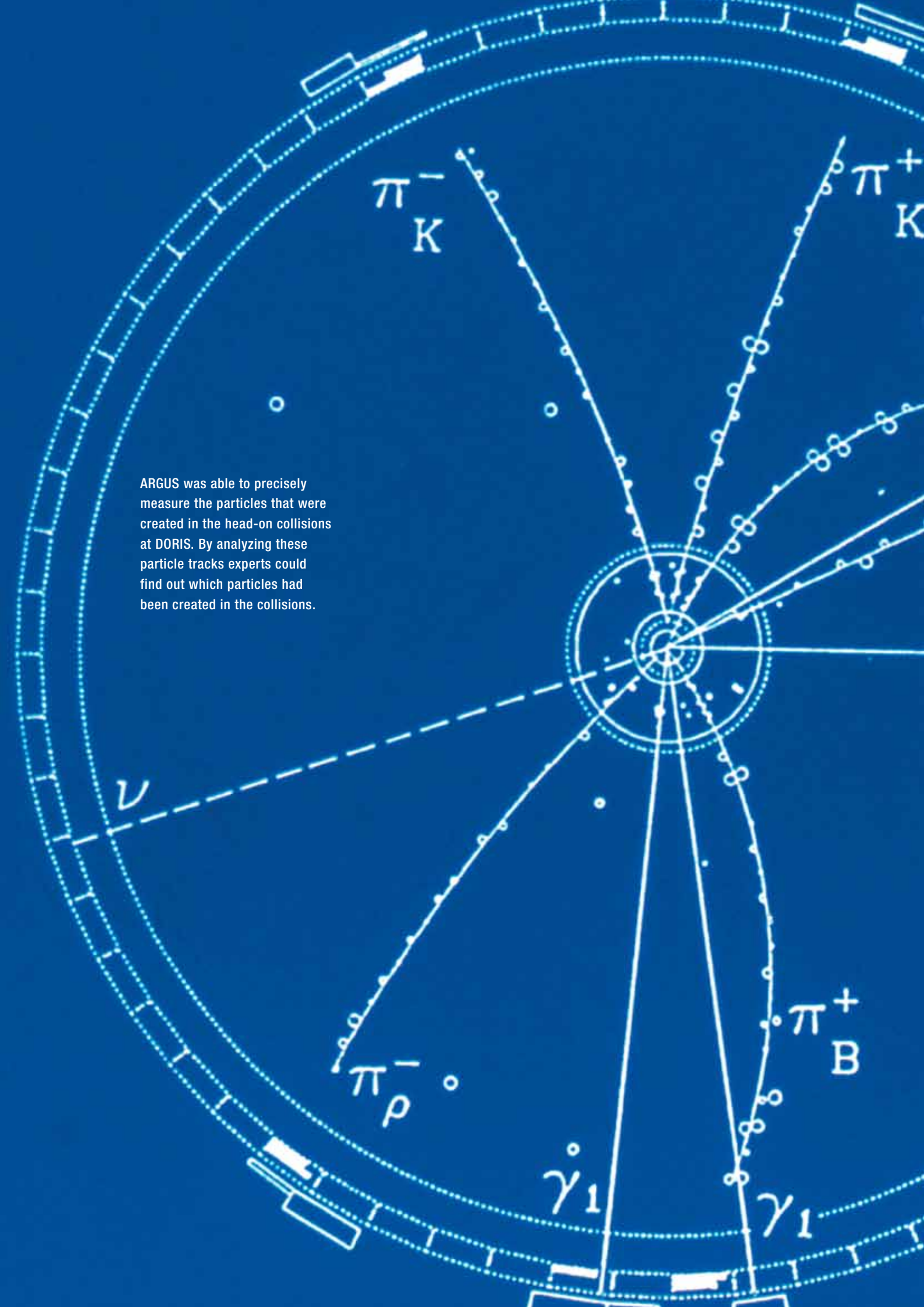
PLUTO was among the first particle detectors at the DORIS storage ring.

In 1974 PLUTO achieved a technological milestone by becoming the first particle detector to operate with a superconducting magnet rather than a conventional one. Superconducting magnets can produce extremely powerful magnetic fields. However, to do so, they have to be cooled to around minus 270 degrees Celsius. The benefit here is that the stronger the magnetic field in a detector, the more precisely the momentum of particles can be measured. Momentum is a key physical quantity.

Superconducting magnets such as the one in PLUTO became a standard feature in particle detectors. Today the technology is used in many experiments around the globe – for example, in the giant detectors at the LHC in Geneva, the world's most powerful accelerator. Siemens also benefited from building the PLUTO magnets: it is now the global market leader for magnetic resonance imaging devices. These tube-shaped machines, which produce 3-D images of the body's interior, are now an indispensable diagnostic tool. The superconducting magnets enable them to generate these sharply focussed images. Siemens' design work for the PLUTO magnet also provided valuable information that enabled the company to build other superconducting magnets.

"PLUTO served as a model for other detectors around the world."

Professor Hinrich Meyer, University of Wuppertal; former member of the PLUTO research group



ARGUS was able to precisely measure the particles that were created in the head-on collisions at DORIS. By analyzing these particle tracks experts could find out which particles had been created in the collisions.

Looking at particles through the eyes of ARGUS

One of the most successful DESY detectors was used at DORIS

The days of particle research at DORIS seemed numbered when the PETRA storage ring went into operation in 1978. With a circumference of 2.3 kilometres, PETRA was much larger than DORIS and could achieve collision energies five times higher. This made a much more precise examination of the microcosm possible. Nevertheless, DESY's Director at the time, Herwig Schopper, felt the smaller storage ring could still be used, provided it was reequipped for a new experiment. The result was the ARGUS detector.

DORIS was thus upgraded to DORIS II in 1982. The upgraded ring produced higher energies and more collisions than DORIS. ARGUS also set new standards for detectors. It was the first experiment in the world that could monitor nearly all products formed in particle collisions. It could also measure the momentum of both charged and neutral particles more precisely than other detectors. In this regard, ARGUS was seven times better than rival detectors in the USA. It also made it possible to develop completely new analysis techniques.

Physicists were thus able to make a series of extraordinary discoveries with ARGUS. For example, the detector registered a rare type of decay of B mesons (particles that contain a b quark). Experts now refer to this as charmless decay. Scientists using ARGUS also discovered new combinations of a b quark with other types of quarks. They were able to define the correct mass of the tau lepton for the first time as well – and also determine its helicity, an important property in quantum physics.

The most important discovery was made in 1987, when ARGUS showed that B mesons often seem to spontaneously transform themselves into their antiparticles. Researchers believed a yet to be discovered particle had to play a role here, and postulated that this would be the top quark – the sixth and heaviest quark. They used the ARGUS data to estimate how heavy the top quark must be. The result turned out to be much heavier than previously expected. The top quark itself wasn't actually discovered until 1995, when it was detected at an accelerator in the USA.

The ARGUS data also played a key role in addressing another key physics question: why does matter exist? Its existence remains a mystery. After all, theory suggests that the Big Bang, which occurred 13.8 billion years ago, should have led to the creation of equal amounts of matter and antimatter, which would have immediately annihilated one another. However, whereas antimatter has apparently been completely destroyed, a tiny portion of the original matter remains; otherwise, we would not exist.

The discovery at ARGUS that B mesons spontaneously transform into their antiparticles marked the starting point for a new field of research. After all, it had become clear that experiments with B mesons could help determine whether or not the Standard Model of elementary particle physics could describe the asymmetry between matter and antimatter in the universe. Subsequent experiments in storage rings in the USA and Japan showed that the Standard Model can only partially explain the irregularity. The mystery of the vanished antimatter thus remains unsolved.

OLYMPUS and the search for protons

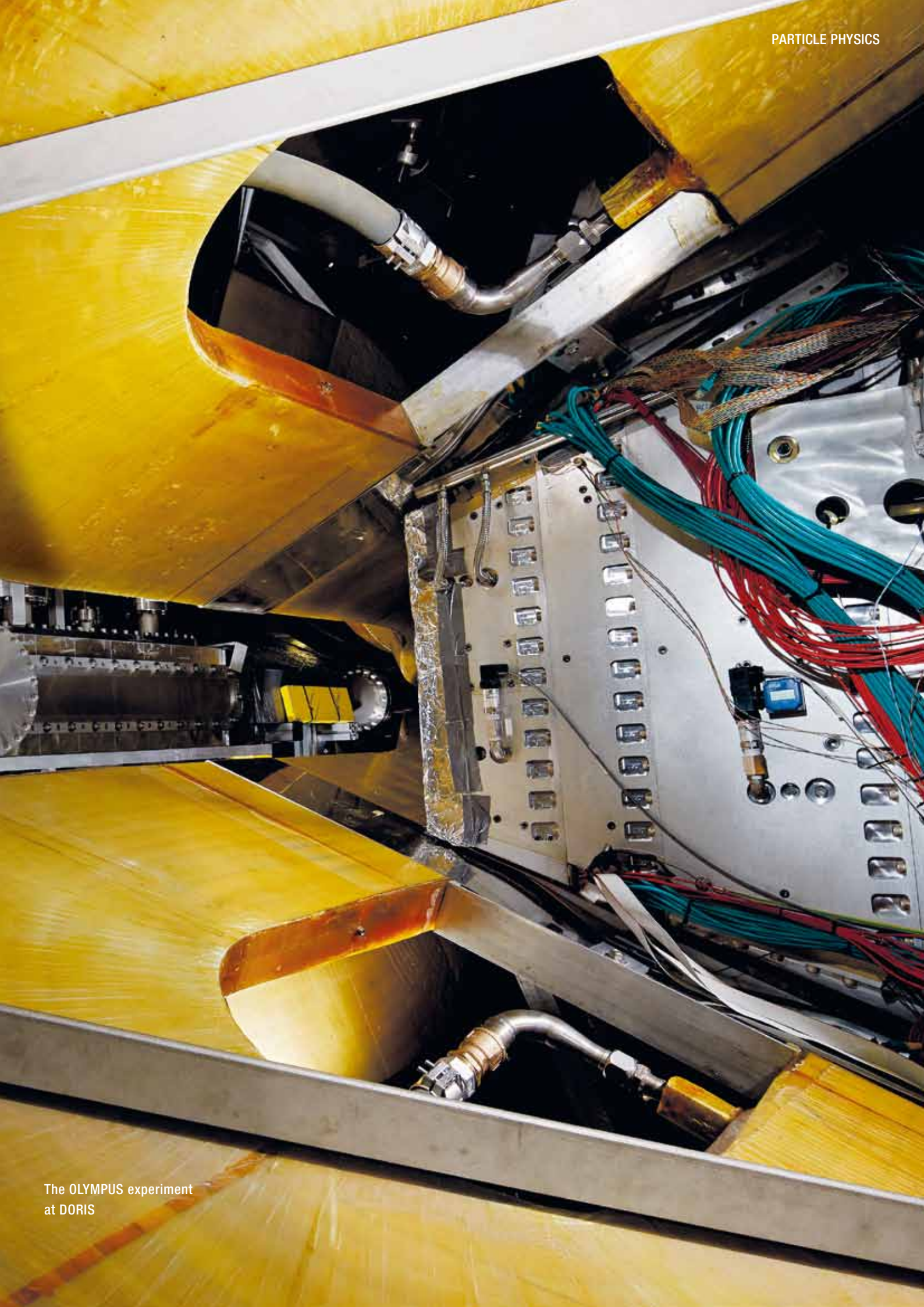
The final DORIS experiment

DORIS was actually built for particle physics experiments. The storage ring was later used as a source of highly intense X-ray beams. The final DORIS experiment marked a return to the facility's roots: until early 2013, the OLYMPUS detector collected data in order to learn more about an important particle: the proton.

The OLYMPUS team consisted of 50 experts from 13 institutes who refined the tried and tested technique of firing an electron at a proton in order to scatter the electron – in other words, divert its flight path. This happens because the two particles affect each other via the electromagnetic force. The effect of this force also leads to the exchange of certain types of gauge bosons known as photons. Such a scattering experiment in the USA a few years ago led to the discovery of a discrepancy, namely that the measurements from the experiment differed from those obtained in previous tests.

One explanation for the deviations was that some scattering processes might cause several photons to be exchanged, rather than just one. This was the theory OLYMPUS was supposed to test. The story behind the experiment is quite interesting. The detector was originally located at MIT in Boston, one of the world's most renowned research universities. However, the university's particle accelerator was shut down in 2005. Even before that, it wasn't capable of accelerating electron antiparticles (positrons). The experts therefore came up with the idea of bringing the detector to Hamburg and installing it in the DORIS storage ring in order to conduct a completely new experiment. DORIS was chosen because unlike most other storage rings, it can alternately fire electrons and positrons at a target. The scientists believed that a subsequent comparison of electron and positron data would enable a precise evaluation of the "multi-photon" hypothesis.

The OLYMPUS detector – a 50-ton facility nearly the size of a house – was shipped to Hamburg in 2010. Only a few adjustments had to be made to fit it into the ring. Data was then taken over a three-month period in 2012. The last set of collision data was collected at DORIS on 2 January 2013. The ring was permanently decommissioned right afterwards. Experts are now analysing the data produced with the experiment and are expected to publish initial results in 2014 at the earliest.



The OLYMPUS experiment at DORIS

RESEARCH WITH PHOTONS

Soon after DORIS started up, the synchrotron radiation produced by the storage ring as a by-product proved to be a valuable research instrument for materials researchers, biologists and many other scientists. In the early 1990s, the accelerator ultimately became one of the leading X-ray sources in the world and attracted many thousands of researchers from around the world to Hamburg.

A wiggler for X-ray production

Exploring the building blocks of life

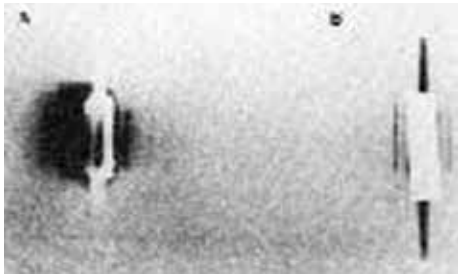
DORIS paved the way for structural analyses of biomolecules

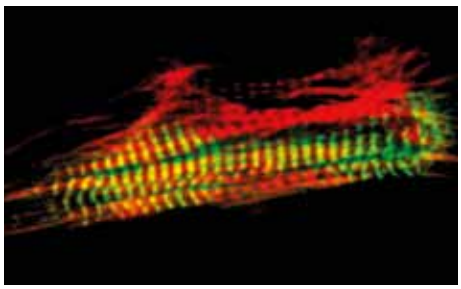
The intense X-ray radiation from an accelerator can be used to examine a great variety of biomolecules in detail. When DORIS started up in 1974, the technology for these investigations was still in its infancy. Over time, however, the methods got better and better. In the late 1970s, DORIS was used to clarify what occurs at the molecular level during muscle movement. Later, experts of the European Molecular Biology Laboratory (EMBL), the Max Planck Society and the University of Hamburg were able to determine the structure of many vital proteins – such as those of the ribosomes, which are themselves the protein factories of living cells. Many of their results and methods are of fundamental importance for experiments at the X-ray sources in use today – from storage rings such as PETRA III and the ESRF to the European XFEL, the most powerful X-ray laser in the world, which will go into operation in Hamburg in 2015.

Why muscles move

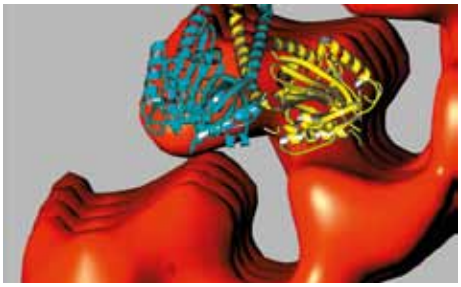
How does a muscle work in detail? How does it turn chemical energy into motion? Early on, biologists developed a plausible theory regarding the exact mechanism: according to this theory, bundles consisting of two types of interlocking proteins – the thick myosin and the thin actin filaments – contract and slide into each other. The interlocking between them causes the muscle movement.

That this theory is correct was proven by researchers of the European Molecular Biology Laboratory (EMBL) in the late 1970s – a breakthrough. They made the protein filaments in muscle fibres visible using collimated synchrotron radiation from the DORIS accelerator. What they found was that the actual engine of muscle movement is the head of the myosin molecule. At the end of it is a small lever arm that swings through its stroke in a fraction of a second when energy is consumed. As a result of this swinging motion, the actin and myosin filaments slide into one another – the muscle contracts.





Above: first biological experiments with synchrotron radiation – diffraction image of an insect muscle in the DESY synchrotron (left) and a conventional X-ray source (right). Below: detail of a muscle cell – green shades mark areas of the giant protein titin whose structure was examined at DORIS by researchers of the European Molecular Biology Lab (EMBL).



Scientists of the Max-Planck Unit for Structural Molecular Biology in Hamburg use DORIS to analyze so-called motor proteins which carry nutrients or chemical messengers into living cells.

Investigating the causes of Alzheimer's disease

As life expectancy increases, Alzheimer's disease is becoming increasingly common. There is still no effective therapy. To find a method of treatment, researchers are trying to understand the fundamental molecular mechanisms underlying memory loss. Studies carried out by a Max Planck working group at DESY have yielded illuminating results in this regard. With the intense X-ray beam of DORIS, researchers analyzed the "tau protein", among other things.

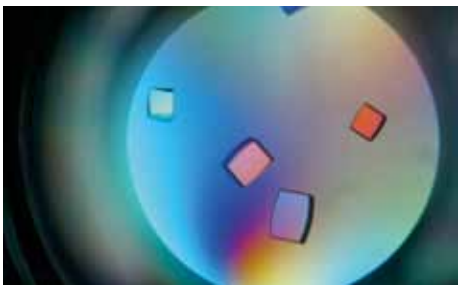
The tau protein has the job of stabilizing the transport routes in a nerve cell. In the case of Alzheimer's disease, however, it stops performing this function. The transport system of the cell collapses; the cell dies. Furthermore, the tau proteins clump together and form some of the harmful deposits characteristically seen in the brains of Alzheimer's patients.

Researchers have succeeded in partially unravelling the underlying molecular processes. Now they are investigating active agents that could prevent the agglutination of these proteins. These would be promising candidates for an Alzheimer's medicine.

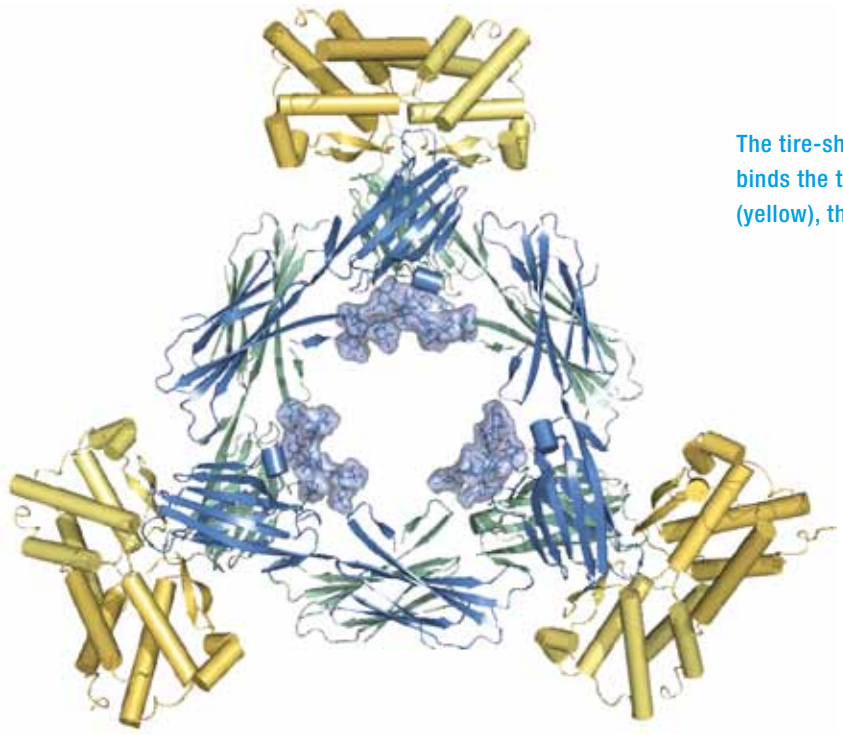
A calcium pump with a turbo switch

Calcium is essential for many biological processes, whether it be cell division, day-night rhythm or communication between cells. One important agent facilitating these processes is a molecular complex that acts as a pump and transports calcium from the inside of a cell to the outside whenever necessary. A Danish-British research team has now unravelled in detail how this calcium pump is switched, in part through experiments at the storage ring DORIS.

The scientists were surprised by the finding: instead of having only the two positions "on" and "off", the pump was unexpectedly found to have a third setting, a sort of turbo switch. This setting enables the molecular complex to shovel considerably more calcium out of the cell, which is important in situations of great stress, for example, when a large amount of calcium has accumulated in the cell. This discovery contributes to a better understanding of a fundamental mechanism in the cell and could eventually enable better treatments for certain illnesses in which the calcium budget is imbalanced.



In order to be able to study the molecular complex of the calcium pump with X-ray radiation, scientists had to grow it into tiny crystals.



The tire-shaped virus protein (blue) binds the three immune proteins (yellow), thereby disarming them.

DORIS reveals how herpes attacks

Herpes is a widespread affliction. Nearly every adult becomes infected with a variant of it in the course of his or her lifetime, although certainly not everyone becomes ill as a result. But how does the virus attack the human immune system so it can settle in the organism permanently? An international team of researchers uncovered an important piece of the answer, and one of the tools they used was DORIS. The experts tracked down an important weapon of the Epstein-Barr virus, a widespread variant of herpes. The Epstein-Barr virus causes infectious mononucleosis, among other things, and is also suspected of causing cancer.

It was long known that the pathogen produces a certain protein with which it disables one of the body's own immune-system proteins. The DORIS experiments played a major role in illuminating this mechanism. Contrary to expectation, the virus protein does not block the active binding sites of the human protein. Instead, it attacks the immune-system protein at a different point and "bends" it so that it no longer functions. The alarm chain of the body's own immune defence is paralyzed; the virus is able to implant itself. This finding suggests starting points for the development of new medicines.

DORIS and the Nobel Prize in Chemistry

Ada Yonath investigated the structure of ribosomes in Hamburg

Stockholm, 10 December 2009. The biochemist Ada Yonath and two colleagues are presented with the most famous award in the world by King Carl Gustaf of Sweden – the Nobel Prize, awarded for determining the structure of the ribosome. The Israeli scientist performed some of the crucial experiments in this endeavour at DORIS. She took a close look at the ribosome, one of the central molecules of life, using the X-ray beam from the Hamburg accelerator.

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

Professor Ada E. Yonath, Nobel laureate 2009

The ribosome consists of several dozen individual molecules and is found in every cell. It has a special function: it serves as a factory that concatenates amino acids into larger molecules – vital proteins. But how does this process work in detail? To understand that, it's essential to know the precise structure of the ribosome – down to the individual atoms, if possible. The method best suited to achieving this is X-ray crystallography. In this approach, the first step is to grow a crystal of the molecules you want to analyze. This crystal is then held into an intense X-ray beam.

From the measurement data, one can then reconstruct the exact shape of the molecule – ideally, atom by atom. The problem for Ada Yonath was that it is extremely difficult to get ribosomes into crystal form. So she came up with a trick: she isolated special bacteria from the Dead Sea, where the water is extremely salty and has a temperature of up to 60 degrees Celsius. The ribosomes of these bacteria proved to be robust enough that crystals could, in fact, be grown from them. It was then possible to analyze these crystals precisely using the X-ray beam of DORIS.

Interior views of matter

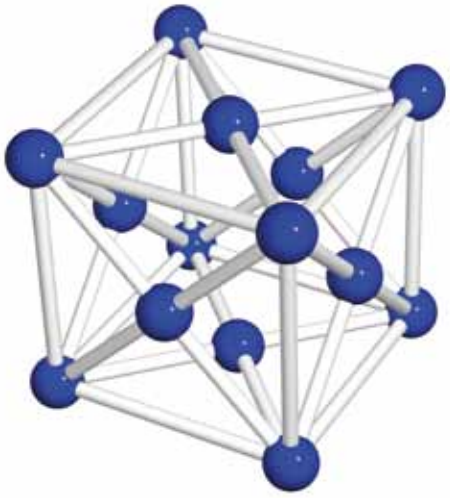
DORIS supplied bright light for fundamental research

The ultra-intense synchrotron radiation from DORIS was suited to one thing more than any other – exploring the basic properties of a large variety of substances. The radiation made it possible to take a detailed look at the microscopic structure of matter. How are the atoms arranged? And how do these atoms react to the exceptionally bright synchrotron radiation? Over time, by answering these questions, DORIS supplied a huge wealth of new fundamental knowledge.

Atomic nuclei in sync

What happens when an iron alloy is strongly heated? DORIS provided the answer. As the temperature increases, more and more atoms in the crystal jump back and forth – an undesirable effect that separates the components of the alloy and makes it unusable. The measurements from DORIS provided important information about how to develop more heat-resistant materials.

And the method for doing so was also developed in part at DORIS: “Mößbauer spectroscopy”, named after the physics Nobel laureate Rudolf Mößbauer. In this technique, X-ray flashes from the accelerator are “swallowed” by the atomic nuclei of the sample and emitted again after a short period of time. If the atoms in the material sample remain in their original positions, this process is synchronous in character. But if the atoms start to jump around in the crystal lattice, the synchronization is lost. This effect can be precisely measured, and experts can use the measurements to draw conclusions about the transport of material within the sample.



Within crystals, atoms (in this case iron) are arranged in a lattice. These structures can be studied in detail with the help of synchrotron radiation.

Magnetic materials under the microscope

Synchrotron radiation is not just bright and concentrated but also has other interesting properties. For example, it can exhibit “circular polarization”, in which case it oscillates in a circular plane. In 1987, a team of researchers at DORIS became the first in the world to use this property for the study of magnetic materials.

The reason that some materials are magnetic can be found at the microscopic level. Their atoms have a certain “spin”. In simplified terms, they behave like tiny compass needles. Synchrotron radiation permits a very precise look at these micro-compasses. With the method developed at DORIS, it became possible, for the first time, to observe the magnetic characteristics of materials at the atomic scale. This method is now being used at several other storage rings around the world.

Basic knowledge for energy-saving lamps

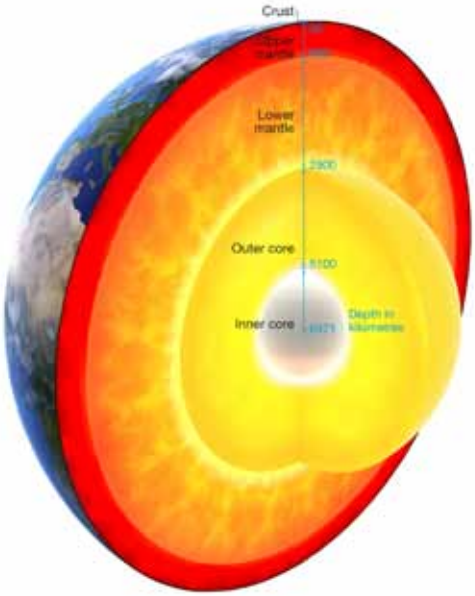
Energy-saving lamps and fluorescent tubes are efficient sources of light, but they contain small quantities of toxic mercury. Inert gases like xenon could be an appropriate substitute. That, however, would require the development of new, specially adapted phosphors that convert the invisible radiation of the xenon into visible light. Using the synchrotron radiation of DORIS, scientists were able to break some important ground in this regard.

Specifically, DORIS supplied a high-intensity ultraviolet beam that acted as a sort of simulation of xenon and excited the phosphors that were being tested as candidates. This allowed researchers to discover which materials are most suitable and whether they are durable enough. The results helped to guide research into new phosphors.

X-ray exposure at high pressure

2,000 degrees Celsius and 250,000 times atmospheric pressure – those are the conditions found at the core of our planet. To understand exactly how the minerals deep inside the earth behave, geoscientists simulated the extreme conditions that prevail there in the laboratory. They used stampers to compress rock samples from several sides at once, then fired the collimated X-ray beam from DORIS into the sample.

An analysis of the scattered X-ray radiation then revealed how the crystal structure of the mineral changes under pressure. The experts discovered, for instance, that olivine, a constituent of the mantle, is transformed into the mineral spinel under pressure. They also studied how viscous artificial magma is at certain pressures; this information is important for understanding how magma accumulates beneath a volcano.

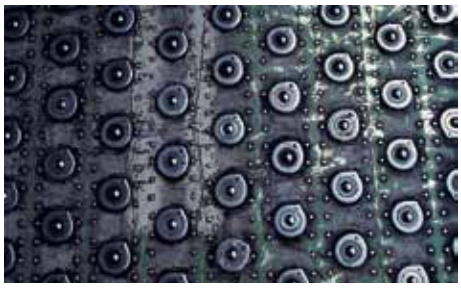


Conditions are harsh at the earth’s core. Geoscientists were able to simulate these conditions at DORIS and analyze mineral probes with X-ray radiation.

New welding techniques for aircraft construction

The Helmholtz-Zentrum Geesthacht investigated new materials at DORIS

Today's materials need to be as light and as strong as possible. In combination, these two properties are vital for many applications, including aircraft construction and the automotive and renewable power industries. To tailor such materials for specific applications, scientists require the most detailed view possible of their innermost structure. That means knowing how the atoms are bonded to one another and whether the material has minuscule cracks or pores.



In aircraft construction, classic rivets are increasingly being replaced with welding techniques. A technique called friction-stir welding, optimized at DORIS, is particularly effective for aluminium alloys used for aircraft construction.

Experiments at DORIS, where materials were irradiated with intense X-rays, provided some of the answers to these questions. Experts from the Helmholtz-Zentrum Geesthacht – Centre for Materials and Coastal Research (HZG), working at their research station at DESY, were able to follow how a weld seam is created. This particular experiment used an apparatus developed by HZG that incorporated a remote-controlled robot which welded together metal plates. The X-ray beam from the accelerator illuminated the welding process as it took place, thereby making visible what was occurring in microscopic detail.

This experiment enabled improvements to techniques such as friction-stir welding, which is used to join aluminium components. Here a special tool is used to heat the material by friction until it becomes soft and can be stirred. The resulting bond then solidifies to form a very strong weld seam.

To optimize this process, it is vital to understand how the material changes according to the speed of the stirring. This is possible with the intense X-ray beam from DORIS.

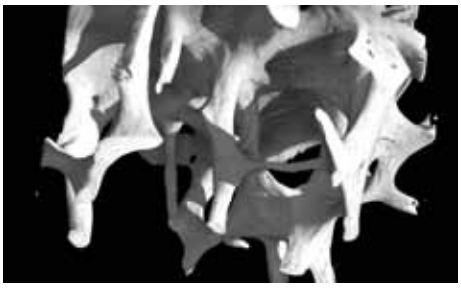
Friction-stir welding is of interest for a variety of applications, including aircraft construction. Today jets are still largely riveted. In future, however, they could be fully welded, which would make them lighter and also cheaper to produce.

High-resolution X-ray images in 3D

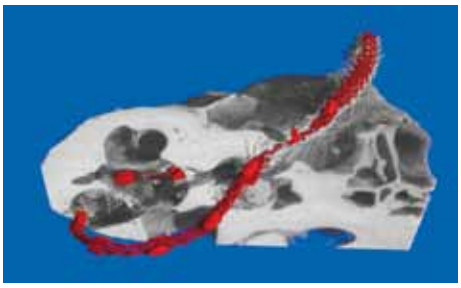
Microtomography with synchrotron radiation

This method is similar to that of a computer tomography (CT) scanner in a hospital, which generates three-dimensional X-ray images of the body's interior. Rather than the X-ray tubes used by a CT scanner, the radiation source for this technique is a storage ring. This generates extremely detailed images at a resolution, in certain cases, of less than one micrometre. Microtomography with synchrotron radiation is a valuable tool in basic research. In a process similar to a CT scan, a sequence of two-dimensional X-ray images are initially generated. A computer then compiles these into a 3-D image.

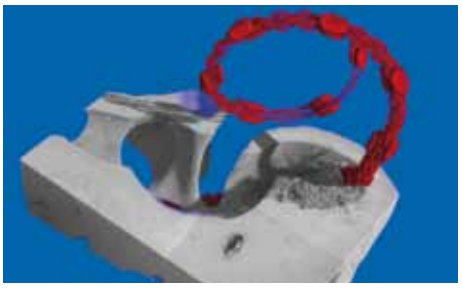
This technique was partly developed at DORIS, where it has been used and continuously enhanced for many years. Over this period, it has helped scientists investigate a vast range of objects and their properties. This includes the precise flow of a metal as it melts during welding and the detailed structure of fibreboard, which is used in making furniture. Other areas of application include the field of biology, where researchers were able to generate images of the tiniest details of internal bone structure, including the course of blood vessels and trabeculae, which are important for a deeper understanding of bone conditions such as osteoporosis. Similarly, they examined the detailed structure of the inner ear and studied the interiors of dinosaur fossils, amphibian skulls, sponges and wasps. Today this method is used at a number of storage rings, including PETRA III, where it is used by the international scientific community for materials research in particular.



3-D image of a bone structure. Microtomography with synchrotron radiation offer a resolution that is a thousand times higher than computer tomography in hospitals.



Microtomography shows the exact placement of an ear implant and the structure of the inner ear and the temporal bone.



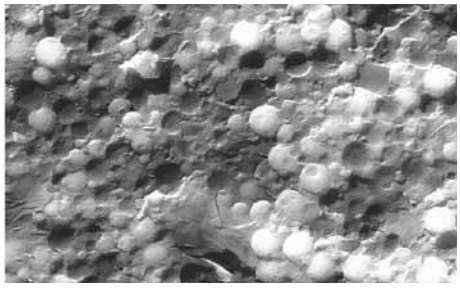
DORIS and industry

Enhancing product development

Industry also recognized the research potential offered by the collimated radiation available from DORIS. Over the years, companies from a wide variety of sectors have conducted experimental work in Hamburg. In particular, manufacturers of catalysts have profited greatly from research conducted at DORIS. Experiments with synchrotron radiation have enabled companies such as Umicore, HaldorTopsøe and IFP to enhance the efficiency of their products, which include catalysts for waste-gas purification systems and for the chemicals and petrochemicals industry.

"Emulsifying agents help stabilize emulsions – mixtures of oil and water – and in doing so form supramolecular structures. The ability to characterize these structures by means of techniques including analysis with synchrotron radiation is vital if we are to enhance our product continuously and achieve an optimal balance between efficacy and biocompatibility."

Prof. Dr. Klaus-Peter Wittern, Head of Research and Development at Beiersdorf AG



A scanning electron microscope image of a water-oil emulsion (Nivea)

Clever cosmetics

Emulsions – fine dispersions of minute droplets of oil in water, or water in oil – are found in every skin cream. Given that these two substances are immiscible, an emulsifying agent is required to stabilize the mixture. Using the intense X-ray beam produced by DORIS, researchers from Beiersdorf AG have been able to investigate how such emulsifiers behave in microscopic detail. This helped determine, for example, how much emulsifier is required to stop a cream becoming too liquid in the heat.

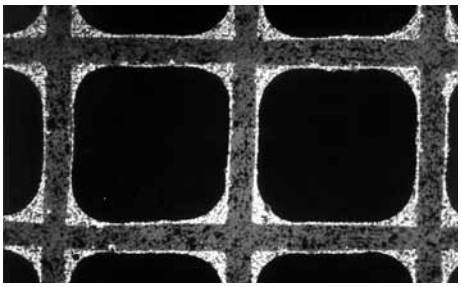
Longer-lasting halogen lamps

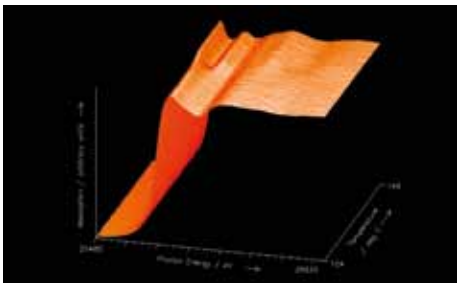
To increase product life, engineers from the lamp manufacturer OSRAM turned to a special X-ay method available at the DORIS storage ring. This enabled them to determine exactly what happens when a commercial halogen lamp incandesces. This in turn gave them some interesting pointers as to how to increase its durability. Before a halogen lamp reaches the store, it is preheated in the factory. This causes the tiny crystallites that make up the coiled tungsten filament to coalesce and form larger granules. This makes the filament stronger and therefore longer-lasting. OSRAM engineers at DORIS were able to observe this process in great detail and thereby gain valuable insights regarding improvements to the production process.

Shedding light on catalysts

Long-standing cooperation with a Danish manufacturer

The Danish company HaldorTopsøe produces catalysts – special substances that accelerate chemical reactions and are indispensable for a host of processes in chemical plants and oil refineries. Over a period of three decades, the company returned regularly to the DORIS storage ring to subject samples to analysis with intense X-rays. One of people chiefly involved was HaldorTopsøe executive Alfons Molenbroek.





In collaboration with industry different catalysts are studies at HASYLAB.
Left: thin cut through a Diesel catalyst; right: absorption data for catalyst microparticle modelling.

What kinds of experiments did you conduct in Hamburg?
A. Molenbroek: The catalysts were manufactured by us in Denmark. Using the facilities in Hamburg, we were able to run through the various chemical reactions and observe them in great detail with the intense X-rays from DORIS. In other words, we were able to watch the catalyst at work – and do so at such a high resolution that we could even see how individual atoms behave.

Which samples did you investigate?
A. Molenbroek: They included catalysts used by industry to produce methanol. These contain substances such as copper, zinc oxide and alumina. Using synchrotron radiation from DORIS, we were able to determine, for example, how the size and also the shape of the minute copper particles change during the reaction. That was important information for us.

What were the major discoveries? And how much did you benefit from experiments at DORIS?
A. Molenbroek: The experiments helped improve our understanding of how our products work. Our ultimate aim was to optimize the performance of our catalysts. To achieve that, we needed to know in as much detail as possible how they work. For this, we applied a whole series of analytic methods. The investigations conducted with the X-ray beam from DORIS provided an important piece of this particular jigsaw puzzle.

Van Gogh in a new light

DORIS deciphers the secrets of art treasures

Does one famous painting perhaps conceal another that the artist once painted on the canvas below? And is the work itself in fact authentic? Similarly, to what extent have its colours faded over the centuries? These are all questions that are of interest not only to art historians. Sophisticated methods of X-ray analysis at the DORIS storage ring have yielded some illuminating answers.

DORIS' X-ray beam makes hidden paintings visible – for example the portrait of a farmer's wife that Vincent van Gogh had covered with the painting of a summer meadow.

In one case, experts had seriously questioned the authenticity of a still life by Vincent van Gogh. Not only was the canvas an unusual size, but the artist's signature was also situated in an odd place. In fact, such was the weight of doubt that from 2003 onwards the painting was no longer assigned to van Gogh. In 2012, however, an international team of art historians subjected the work to an even more detailed scrutiny, using a new type of X-ray analysis at DORIS. And indeed, this method showed that the pigments in the painting were of exactly the same type as those used in other works by van Gogh. Moreover, the experts were able to identify the artist's characteristic brushwork in a scene that he had painted over when composing the still life. As a result, the owner of Still Life with Meadow Flowers and Roses – the Kröller-Müller Museum in the Netherlands – is once again authorized to display the work as a genuine van Gogh.

DORIS was also involved in helping solve another art mystery. For a long time, art historians were at a loss to explain why the colours in some works progressively fade in brilliance. The vivid yellow used by van Gogh for his sunflowers, for example, has gradually transmuted into a nondescript brown. Analysis conducted at DORIS and other lightsources revealed that the pigment in question, chrome yellow, had changed chemically, mainly as a result of the influence of light and of substances from other pigments. Subsequently, it was discovered that green and blue light has a particularly detrimental effect. In order to avoid further colour deterioration, the experts advised against illuminating the works with LED lamps, which have a spectrum that contains relatively powerful, and therefore in this context harmful, blue light.

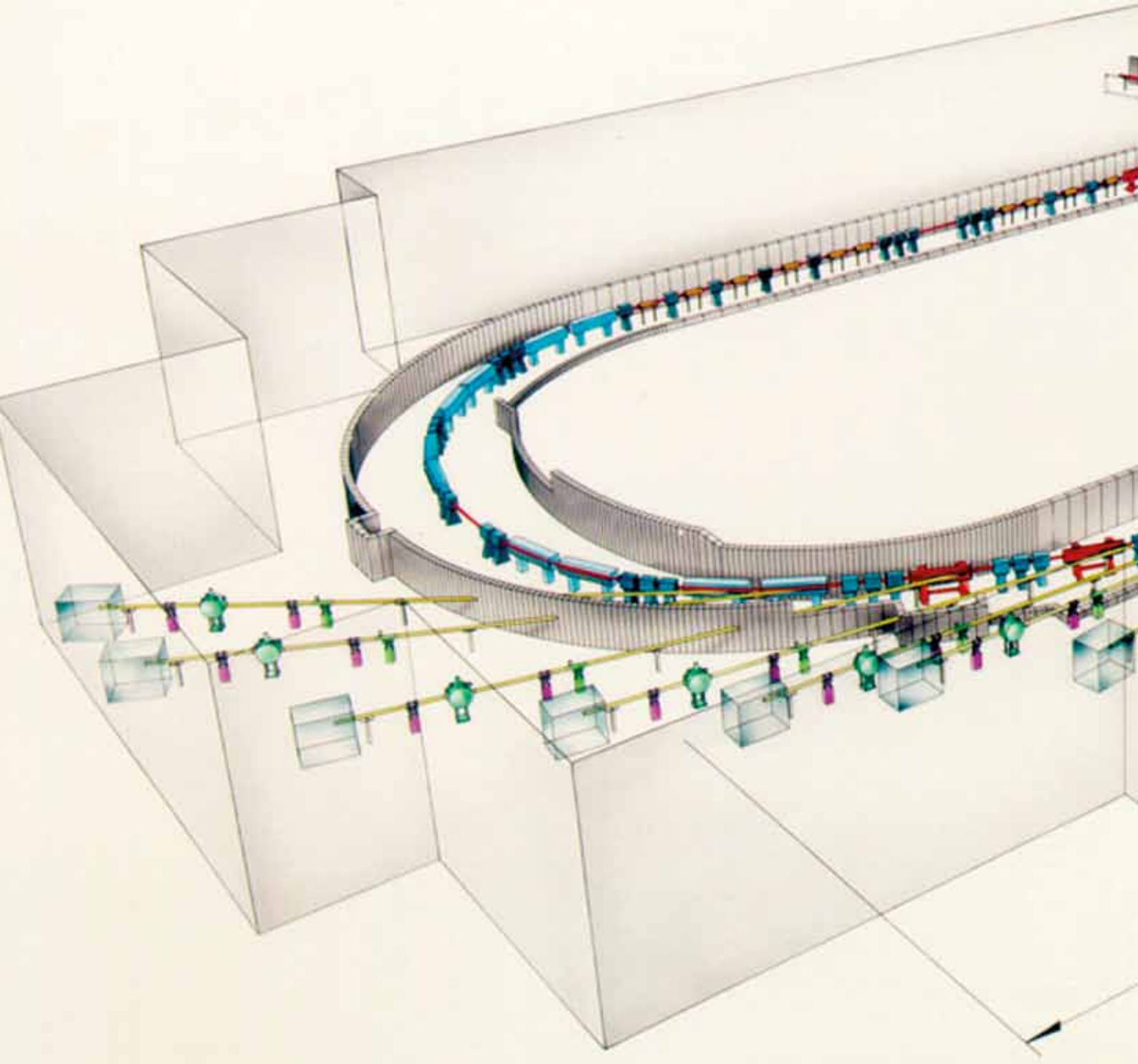
The origins of the blacksmith's art in northern Europe

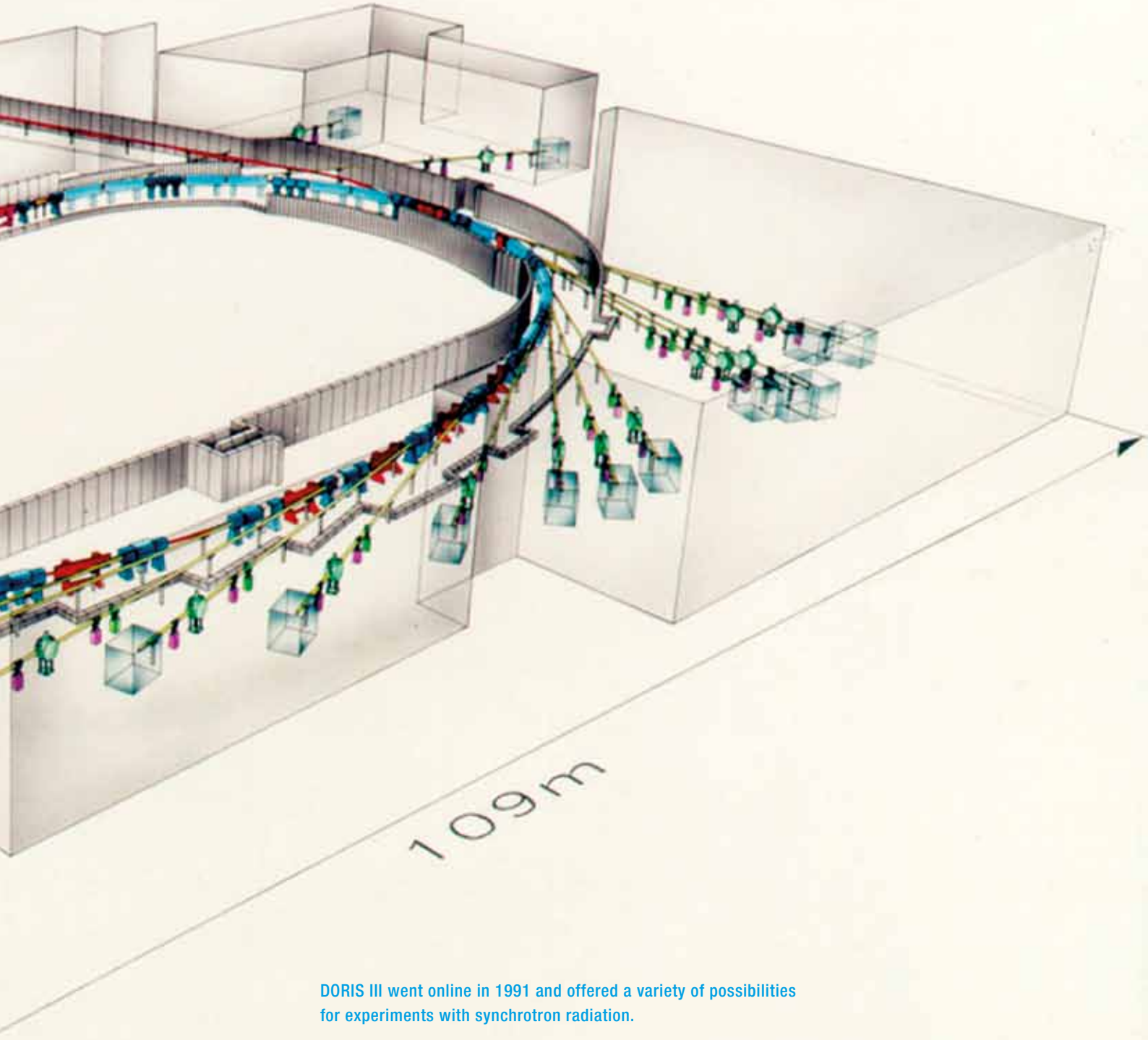
Archaeologists at DORIS investigate Stone and Bronze Age axe heads

For the archaeologist, ancient burial sites are veritable treasure troves. They almost always yield objects that provide all kinds of fascinating insights into the life and ways of our ancestors. Axe heads are a common find in archaeological excavations from the Stone and Bronze Ages (2500–1350 BC), both as weapons in burial sites and as tools forming part of a sacrificial offering. Yet do such finds represent genuine period artefacts? The question is by no means irrelevant, since in the 19th century it was not unknown for fake relics to be secretly deposited at such sites with the aim of enhancing their value in the eyes of the authorities.

Today, the question is how to identify the genuine objects. By happy coincidence, experts from the archaeological museum Schloss Gottorf fell into conversation with physicists from DESY and thereby discovered that synchrotron radiation would be an ideal method of analysis for their purposes, not least because it leaves the object of investigation completely intact. The archaeologists investigated the chemical composition and the microscopic structure of the relics at DORIS. This revealed that several items were in fact fake. The archaeologists discovered that not only was the tin content too high, but also that while the axe heads bore signs of forging on the outer surface, there were no corresponding deformations within. In other words, they were evidently castings made from old axe heads. The experts are also busy unravelling another archaeological conundrum: the existence of specially shaped stones from late Stone Age Europe. Were these stones perhaps used for forging metal – a technique that would have been revolutionary in the Stone Age? To test this hypothesis, archaeologists made replicas of these stones and then used them to forge the replica axe heads. The replica axe heads were then examined and compared with the originals using the X-ray beam from DORIS. In this way, the experts obtained information about how closely the marks left by the stone tools and the inner structure of the original artefacts compared with those of the replicas. The outcome of this work, which is being continued at PETRA III, may well help answer a fascinating question: From what period onwards was metal forged in these latitudes in order to make weapons and tools harder and stronger?

Cult object, tool or weapon? The 'axe of Ahneby' was studied with DESY's X-ray beams. It stems from the Bronze Age.





DORIS III went online in 1991 and offered a variety of possibilities for experiments with synchrotron radiation.

- DORIS: Ring accelerator for electrons and positrons
- Length: 289 m
- Start-up: 1974
- 1974 – 1992: Particle physics and research with synchrotron radiation
- 1993 – 2012: Source for synchrotron radiation
- 36 measuring stations with 45 interchangeable instruments

IMPRINT

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Kick-starting the brain: table football provided a creative break for hard-working scientists in the HASYLAB experimental hall.

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