50 Years of DESY
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Log book

INSIGHT STARTS HERE.
DESY is one of the world’s leading centres for the investigation of the structure of matter. DESY develops, runs and uses accelerators and detectors for photon science and particle physics. DESY is a national research centre supported by public funds and member of the Helmholtz Association.
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BACK TO THE FUTURE

DESY turns 50
Normally, scientists look toward the future. That’s part of their job. After all, those doing cutting-edge research are moving into unexplored territory, discovering new things and coming up with answers to fundamental questions that will make a major impact on our future. However, sometimes it’s worthwhile to take a look back at the history of research, which can be very exciting. That is certainly the case for the history of the DESY research centre based in Hamburg and Zeuthen.

Fifty years ago, on 18 December 1959, the foundation charter of DESY (for Deutsches Elektronen-Synchrotron), was signed in Hamburg City Hall. At that time, the idea was to establish a national research centre for particle physics, an umbrella organization for perhaps two or three hundred specialists. In retrospect, it is clear that the founders’ plans were much too modest! Today, DESY is an incredibly multifaceted and innovative research centre.

Approximately 3000 scientists from all over the world work here or come to Hamburg and Zeuthen regularly as guest researchers. They do their research in a broad range of areas. Some are looking for the tiniest elementary particles – in other words, the basic components of the universe – using gigantic high-tech accelerators and detectors, or alternatively paper, pencils and superfast computers.

Others are investigating exactly how tiny protein molecules work in order to gain essential data for the medicines of tomorrow. Still others are creating the foundations of nanotechnology, analysing materials that display completely new properties, or sending back “live” reports from the world of nanoparticles.

In this brochure you will find out how in the course of decades DESY became what it is today. Like a time machine, it will take you through the different eras of its history – from its modest beginnings in the 1960s through the construction of the giant accelerator HERA in the 1980s and all the way to the world’s brightest X-ray sources, which are attracting crowds of experts from all over the world and will continue to do so in the future. The stories of what was going on behind the scenes are especially exciting and sometimes even amusing. That is because progress at DESY has again and again “happened” not in a straightforward way but on unpredictable, winding paths trodden by outstanding, highly individual people.

Wilhelm von Humboldt used to say that the only people who have a future are those who know their past. So it makes perfect sense for us scientists to once in a while take a look at our own roots. I hope that this look will also be worthwhile for you, our readers.

Sincerely,
Helmut Dosch
01: FOUNDATION

How DESY was established on a former drill ground

PHYSICS ON THE GRINDSTONE
Physics on the grindstone

How DESY was established on a former drill ground

Hamburg, 18 December 1959. On this day, a small but significant ceremony was held in the City Hall as the Federal Minister of Nuclear Energy and Water Management, Siegfried Balke, and Hamburg’s Mayor Max Brauer solemnly signed a state treaty. This document formally established a new research centre: the Deutsches Elekronen-Synchrotron, or DESY for short. This independent foundation was set up under civil law to find out which fundamental particles matter consists of and what internal forces hold the world together.

But the story actually began before that, in the mid-1950s. Researchers and policymakers all over the world had realized that a new and extremely exciting field of science was opening up, one that promised to yield many fundamental discoveries: particle physics. The USA dominated this new field, and it already had a number of particle accelerator centres. In order to stay abreast of these new developments, the Europeans established the European Organization for Nuclear Research CERN in Geneva, Switzerland, in 1954. Countries including France and Italy planned to set up their own national particle accelerators in order to offer their physicists local research opportunities.
German physicists did not want to be left out of this trend. Conditions seemed to be favourable for the foundation of their own centre for particle research. Germany had just had part of its sovereignty restored. And the country’s newly established Federal Ministry for Nuclear Energy and Water Management, which at that time was responsible for fundamental research in physics, had funding available and was open to calls for a new large-scale scientific project.

The only question was: what should this project look like? The answer to this question was to be determined at a conference in Geneva in June 1956. Here, a group of the most important particle researchers in Germany at the time met in a working session to design an initial sketch of a new device: a ring-shaped accelerator of the synchrotron type with a circumference of 300 metres for accelerating electrons to an energy of 6 GeV (1 giga-electronvolt = 1 billion electronvolts). That was a new record value and the highest energy researchers could hope to reach at that time with an electron synchrotron. This machine was to complement the large proton accelerators that were then being built at CERN and in the USA. Together with the concept, the group also came up with the name of the new research centre: Deutsches Elektronen-Synchrotron DESY.

Soon after that, an official working committee began the concrete planning for the centre. It was headed by the internationally renowned physicist Willibald Jentschke, who had come from the USA to the University of Hamburg specifically to work on the new project. But where in Hamburg should the accelerator be located? This was not a trivial question, because it involved the construction of a complete research centre consisting of a synchrotron, experimental halls, workshops and office buildings.
The solution was found in the Bahrenfeld district of Hamburg, where there was a large open space that had long ago been named “Hungerkamp” on account of the infertile layer of sand covering it to a depth of 35 metres. Since the late 19th century, this piece of wasteland had been used by various regiments as a drill ground. More than once, His Majesty Kaiser Wilhelm II reviewed military parades on this drill ground, which was also known as the “Big Grindstone”.

In 1927, during the Weimar Republic, the drill ground in Bahrenfeld was converted into a military airfield. After the end of the Second World War, most of this complex lay unused. The airfield belonged to the German Ministry of Defence, but the German Air Force, which was newly constituted in 1956, had no use for it, as it was not large enough and lay too close to the Hamburg-Fuhlsbüttel civil airport. That was fortunate for the DESY planners. The complex had great potential for expansion, and apart from a few erratic blocks of stone the sandy subsoil was almost ideal for the construction of an accelerator.

The initial construction work began in 1958, even before the centre had been officially established. “The devices that are to be installed in Bahrenfeld have frighteningly large dimensions,” wrote a reporter for the Hamburger Abendblatt in an article about a topping out ceremony held on 23 October 1958. “But no one needs to be afraid of them, because they generate only tiny amounts of radiation that cannot cause any damage.”

In early 1959 the foundation stone was laid for the ring tunnel building that was to accommodate the accelerator. And on 18 December 1959, when Siegfried Balke and Max Brauer signed the state treaty, the first DESY building in Bahrenfeld was already finished. It was a multipurpose building that served as a dormitory for the scientists, an administrative centre and a canteen.
Construction starts.
**DESY’s architect**

Willibald Jentschke is known as the founding father of the Deutsches Elektronen-Synchrotron

Viennese charm, diplomatic astuteness and a touch of cheek – these are the outstanding attributes of Willibald Jentschke, the most important figure of DESY’s founding era. “Without Jentschke the research centre would never have been built,” says Erich Lohrmann, who started work at DESY as a young physicist in 1961.

Jentschke, who was born in Vienna, Austria, in 1911, had made a name for himself in the USA as an expert in the fields of nuclear physics and accelerator construction. In 1954 he received a very tempting offer from Germany. The University of Hamburg offered him a professorship – and the prospect of building up a new physics institute, complete with a major scientific facility. For a year, Jentschke negotiated with the Hamburg city authorities regarding the conditions for this construction project. His skill as a negotiator was to become legendary. In every new round of negotiations he increased his demands, until the Hamburg Senate in August 1955 approved 7.35 million deutschmarks in research funding – an unheard-of amount at that time, and one of the financial cornerstones of DESY.

In summer 1956 Willibald Jentschke moved to Hamburg and began to put together his team of enthusiastic, though mostly inexperienced, physicists. “When it comes to the construction of a large-scale accelerator, we were rank amateurs,” says Lohrmann. “But we compensated for our lack of experience with our tremendous enthusiasm.”

Jentschke’s leadership style was to have a long-term impact on the spirit of the laboratory. “It’s true that he always had something of a Vienna privy councillor about him,” recalls Lohrmann. “But he made sure that there was always an atmosphere of tolerance and solidarity at DESY. And we can still feel that spirit today.”

When DESY was officially founded in December 1959, Jentschke became Chairman of the DESY Directorate. He retained this position until 1970, when he moved to Geneva to serve as Director-General of CERN. By his own admission, Jentschke has always regarded particle physics as the most fascinating of all scientific disciplines. “The question might arise whether these efforts and this tremendous expenditure of human labor and material are justified. By way of an answer we must say that nature demands that we make this effort if we wish to penetrate her deepest secrets,” he says. “Doing research with these machines is a tremendous adventure. After all, we’re trying to discover the innermost structure of the building blocks that we ourselves consist of. The objective of our work is not to investigate a partial area of physics but to explore the structure of the world as a whole.”
The bubble chamber at the DESY synchrotron.
THE PARTICLES START TO ORBIT
The particles start to orbit

Pioneering achievements with the DESY synchrotron

Just before midnight on 25 February 1964, the atmosphere among the DESY physicists crowding into the brand-new control room of the synchrotron was so tense that you could have heard a pin fall. Would the accelerator that they had worked on for almost a decade function as planned? Now it was time for the crucial test. The experts at the controls manipulated their switches and control knobs. A short time later, a brief flicker on the recording instruments indicated that their work had led to a resounding success. The electron beam had raced through the 300-metre-long ring-shaped vacuum pipe 8000 times, reaching an energy of 2.5 GeV at the end of its travels. Just one day later, the physicists attained a value of 5 GeV – almost the maximum energy of the synchrotron.
It was by no means inevitable that the first DESY particle accelerator would be brought to the operational level so quickly and without any major problems. It is true that DESY Director Willibald Jentschke had managed to attract a large group of highly motivated young physicists and engineers to Hamburg. However, most of these experts had no experience whatsoever that was relevant to the construction of a particle accelerator. The challenges were tremendous. For example, the magnets that keep the speeding electrons on course had to be positioned with a precision of a few tenths of a millimetre and kept in these positions permanently.

Fortunately, the young DESY team was able to spend a lot of time looking over the shoulders of the accelerator builders in the USA and at CERN in Geneva. As a result, the team in Hamburg succeeded in setting up a new research centre costing approximately 100 million deutschmarks that boasted one of the most powerful electron synchrotrons of the 1960s. In 1964 the DESY synchrotron and a facility in Boston offered by far the highest electron energy in the world: 6 GeV, or 6 billion electronvolts. This enabled researchers to use the facility to study protons (hydrogen nuclei), for example, with a precision that had previously been unheard of.
How does a synchrotron work?

It all begins with the “electron gun”. When a metal wire is heated up, it generates tiny electron bunches consisting of tens of millions of individual electrons. In an initial step, a linear accelerator – which is basically a very large television tube – brings these bunches up to a certain speed. It is difficult to start up a car if it is in fourth gear, and similarly it is much easier to shoot electrons into a synchrotron if they have already reached a certain base speed. Inside the synchrotron the particles move at virtually the speed of light – almost 300,000 kilometres per second – in a vacuum tube that is as thick as a man’s arm.

At certain points the electron bunches receive a mighty push from strong radio waves. This is the actual acceleration process, in which the electrons gain very little speed but a great deal of energy. To ensure that they do not fly out of the curve in the same way a car does when it is going too fast, they are kept on their circular course by massive electromagnets. As a general rule, the more kinetic energy the electrons have, the stronger the magnetic field of the deflecting magnets has to be.

In other words, the magnetic field and the energy of the electrons must always match. In a synchrotron, this equivalence is maintained automatically. The electrons’ energy in effect regulates itself so that it is synchronized with the magnetic field – hence the name “synchrotron”.

After only a hundredth of a second and 10,000 circuits around the ring, the electrons have reached their maximum energy. At that point they are steered into the experimental halls and shot at a target. The energies reached by these speeding electrons are measured in a special unit called the electronvolt, or eV for short. An electronvolt is equivalent to the energy received by a single electron when it crosses an electric field of exactly one volt. The vacuum tube in a television set generates approximately 10,000 eV. In 1964 the DESY synchrotron generated 6 billion eV. And the ILC, a gigantic next-generation accelerator that is still in the planning stage, is expected to boost electrons to an energy of 250 billion eV.
In fact, the actual experiments were not performed in the accelerator itself but in the adjacent experimental halls. The electron beam, which almost reached the speed of light, was steered into these halls so that the physicists could conduct their research on a “target”. One such target consisted of liquid hydrogen; another was a diamond as big as a thumbnail – but black, and therefore completely useless as a piece of jewellery.

When the speeding electrons hit the target, they generated extremely high-energy radiation. Called bremsstrahlung, this radiation could then transform into exotic short-lived particles. These exotic specimens (or fragments of them) could be identified by means of special detectors, such as a bubble chamber. This was a tank filled with a substance such as liquid hydrogen in which the particles left tiny but clearly visible bubbles along their flight path.

It did not take long for researchers to come up with their first scientific results. A team of young researchers won the physics prize of the German Physical Society for their measurements with so-called polarized photons. One of the findings even made it into the headlines of the mass media. The DESY physicists were the first ones to create an antiproton – in other words, the antiparticle of the hydrogen nucleus – with the help of extremely high-energy gamma radiation. On its first page, the 10 December 1965 issue of the Bild Zeitung tabloid announced: “Sensation in Hamburg: Antiparticles made of light”.

Experiments using the synchrotron were carried out until the end of 1978, but that was not the end of the machine’s useful life. After several rounds of restructuring and renovation, it is still being used today as a pre-accelerator for the other rings in Hamburg and as a test facility for assessing the performance of new components for detectors.

Over the years, the synchrotron has delivered countless data – not only for the researchers at DESY but also for physicists in other parts of Germany and abroad. Even the German Democratic Republic’s Institute for High-Energy Physics in Zeuthen was involved in bubble chamber tests. It was a remarkable cooperative effort right in the middle of the Cold War era, and it came to pass thanks to personal contacts formed at CERN.
AN ELECTRON MARATHON
An electron marathon
DORIS, the first storage ring at DESY

When DORIS was being planned, physicists were still trying to determine whether particles such as protons and neutrons are made of even smaller particles. An idea had been circulating since the early 1960s, according to which protons, neutrons and similar particles were composed of tiny constituents called quarks. This hypothesis remained highly controversial into the 1970s. A number of researchers considered the quarks, with their strange, fractional charges, to be little more than mathematical auxiliary constructs. It took the spectacular results achieved in a storage ring in California and at DORIS in Hamburg to convince the last of the sceptics that quarks really do exist.

In the 1980s, following the reconfiguration of DORIS into DORIS II, the ARGUS detector made another spectacular observation: B mesons – particles that contain a b quark – can spontaneously transform into their antiparticles. This transformation in some mysterious way had to involve a particle that had not yet been discovered – the top quark, the sixth and heaviest of all quarks. With the help of ARGUS, scientists were able to reliably estimate for the first time roughly how heavy the top quark must be, which turned out to be much heavier than previously expected. The top quark was not discovered until 1995 in what at the time was the most powerful accelerator in the world: the Tevatron in the USA.

1964. The DESY synchrotron was barely in operation when “Group H”, a sort of think tank, was established with the mission to ponder the future of the research centre DESY. If the Hamburg laboratory was to firmly establish itself as one of the world’s leading particle research facilities, sooner or later it had to begin thinking about a new, more powerful accelerator. Just two years later, Group H reported back with a bold suggestion. Instead of building a larger synchrotron, the group recommended the construction of what at that time was still a very new and immature accelerator type: a storage ring.

The reason for the daring recommendation: a storage ring, in which two particles collide head-on at full speed, promised to deliver significantly higher collision energies than a synchrotron. But the technology was brand new and not yet well tested. It was only in 1962 that the first electron-positron storage ring ever had been built in Italy. Just a few meters in circumference, it was little more than a toy. A large storage ring hundreds of metres in circumference did not exist at that time. Whether such a machine would produce anything of scientific interest was highly uncertain.

On the trail of the quarks
What DORIS has contributed to physics

When DORIS was being planned, physicists were still trying to determine whether particles such as protons and neutrons are made of even smaller particles. An idea had been circulating since the early 1960s, according to which protons, neutrons and similar particles were composed of tiny constituents called quarks. This hypothesis remained highly controversial into the 1970s. A number of researchers considered the quarks, with their strange, fractional charges, to be little more than mathematical auxiliary constructs. It took the spectacular results achieved in a storage ring in California and at DORIS in Hamburg to convince the last of the sceptics that quarks really do exist.
A not insignificant number of DESY researchers therefore thought it better to stick with the proven technology and to instead build a larger synchrotron. According to one expert opinion from that time, building a storage ring would not be worthwhile, and this proposal should not be pursued. The fact that the responsible persons at DESY nevertheless chose the riskier variant had more to do with a gut feeling than with any convincing argumentation. Their daring would soon be richly rewarded.

Construction work for the new accelerator began in 1969. Its circumference was specified at 288 metres; its shape resembled the running track of an athletics stadium – two curves connected by two straight segments. The machine was to comprise two superimposed accelerator beam pipes, one for the electrons and the other for the positrons circling in the opposite direction. This double structure gave the child its name: DORIS (DOUBLE RING STORAGE FACILITY).

Even before DORIS was completed in 1974, two other storage ring facilities had already proved that the new accelerator concept truly was suitable for exciting science and could indeed be used to accelerate particles effectively. Then, just before the measurements in Hamburg commenced, came the bombshell announcement that a spectacular discovery had been made at two accelerator facilities in the USA: the researchers found a new quark known as the charm quark. The discovery would go down in the history of physics as the “November Revolution”, and resulted in the Nobel Prize in Physics for the discoverers, Samuel Ting and Burton Richter.
What is a storage ring?

The name says it all: unlike in a synchrotron, the particles (for example electrons) in a storage ring are not simply accelerated briefly and then immediately fired at a target. Instead they run around a ring with maximum energy for hours. In addition, other particles — typically positrons, the antiparticles of electrons — are travelling just as fast in the opposite direction. These particles then collide with full force at certain locations along the ring. Electrons and positrons annihilate one another in a tiny, but very dense, burst of energy. Among the things that can be generated from this ball of energy are exotic particles such as heavy quarks.

The larger the storage ring is, the greater the collision energy it achieves, and thus the heavier and more exotic the particles that are generated during the collisions. There are several types of storage ring: some fire electrons and positrons at one another; others accelerate hydrogen nuclei (protons). The HERA accelerator at DESY combined both types and fired electrons at protons.

Other storage rings accelerate electrons exclusively without having them collide with one another. These are not used for particle physics research, but as sources for synchrotron radiation, in particular X-ray light.

Storage rings were the dominant type of accelerators of recent decades. The LHC in Geneva, Switzerland, currently the most powerful accelerator in the world, is also a storage ring, namely for protons. Physicists are, however, turning to a new type, the linear collider, for the next generation of electron accelerators. The linear collider will use two perfectly straight, opposing accelerators to collide electrons with positrons. This eliminates undesirable energy losses in the form of synchrotron radiation, which is generated when charged particles fly around curves.
A veritable particle gold rush followed, in which DORIS played a prominent role and made several important contributions. It was this phase that established the quark model in the heads of physicists once and for all. It was like the bursting of a dam – the dawning of “new physics”. After the fifth quark, the bottom quark, was discovered in the USA in 1977, the decision was taken in Hamburg to modify the DORIS accelerator in order to investigate the properties of this new b quark. That same year the double ring became a single ring, which brought with it certain technical advantages.

Then in 1981 DORIS was modified and rechristened DORIS II. The particle physicists replaced the magnets, increased the energy to 5.6 GeV and installed ARGUS, a brand new, state-of-the-art detector specialized in the analysis of B mesons, which are particles that contain a b quark. A second group of researchers also began playing an increasingly important role – the users of synchrotron radiation. This is the radiation generated quasi as a by-product of accelerator operation. It can be used extremely effectively to illuminate and analyse a wide variety of materials.

DORIS II was then upgraded to DORIS III in 1990, making it the brightest X-ray source in Europe at that time. It remains in operation today, each year attracting roughly 2000 guest scientists from all over the world who seek to use the focused radiation to analyse a wide variety of specimens down to the smallest detail.
Some careers in particle physics begin with a fleeting visit – such as that of Rolf-Dieter Heuer, former PhD student at DESY and today the Director-General of CERN in Geneva. After completing his diploma at the University of Stuttgart, Germany, Heuer only wanted to take a quick peek at his new place of work at DESY as PhD student from the University of Heidelberg. Suitcase still in hand, he was immediately drafted to do a night shift of the DESY-Heidelberg experiment at DORIS. The shift leader: a certain Albrecht Wagner…

Heuer has developed, built, analysed and managed particle physics experiments ever since, always with a healthy dose of curiosity, and has risen through the ranks from PhD student to post doc, group leader, spokesman for the OPAL collaboration at CERN, professor at the University of Hamburg, and Research Director at DESY to become Director-General of the world’s largest centre for particle physics, CERN. “The best job in physics,” he admitted during an interview with a reporter from The Economist. To be Director-General presiding over the start of the Large Hadron Collider LHC, the first collisions and probably the first discoveries – the long-awaited Higgs particle, for example – is incredibly exciting for a dyed-in-the-wool particle physicist.

“I apparently have a knack for people,” says Heuer. His motto: you have to step back and put those people who perform the work into the spotlight. “Trust is incredibly important,” adds Heuer. Experiments cannot be innovative and efficient without young scientists, and new ideas are always welcome under Heuer provided that they are well-founded. “I learned that from Björn Wiik, the father of HERA and TESLA. With him the ideas came first, then the resources. I would like to introduce that same spirit here at CERN.”

The collaborative structures that Heuer puts into place where he works run smoothly. He is often the mediator between worlds, for example as the trailblazer for the LHC computing nodes in Karlsruhe and at DESY or as the father of the Helmholtz Alliance “Physics at the Terascale”, which brings together all of the German universities and institutes participating in the LHC and ILC. Heuer is not the only one, however, who worked his way up from the “rags” job at the DORIS accelerator to upper management in physics. Accompanying him every step of the way since the early 1970s and his forerunner in the DESY Directorate was his former shift leader at DORIS, Albrecht Wagner.
Walter Schmidt-Parzefall headed the ARGUS project in the 1980s. The detector at the DORIS storage ring is among the most successful experiments in the history of DESY.

**What were the outstanding characteristics of ARGUS?**

ARGUS was able to observe almost all of the particles generated during the collisions. It was also able to measure the momentum of the particles much more accurately than any other detector in the world. This required that we use the largest magnetic coil possible, however. The coil was so large that the detector magnet just barely fit inside the interaction zone of DORIS. We also had a very large electricity bill as a result. However, the bill was slightly mitigated by the fact that we could heat the building from the waste heat of the coil.

**How large was the team back then?**

Initially the team was very small, comprising maybe 25 people during the construction phase. Over the course of time, however, more and more scientists joined the team, until finally there were around 100 members. They came not only from German universities, but also from abroad. From Sweden, Canada and the USA, for example. A group from Russia also played a very important role, which at the time was still very exotic. But Schopper wanted to open the Iron Curtain and made use of his contacts. Communication and travel were not easy during the Cold War, of course, but still we managed. ARGUS ran for a total of about ten years and delivered a wealth of scientific results. This is reflected by the fact that members of the ARGUS team were invited to more than 100 lectures a year all over the world.

Measurements with the ARGUS detector commenced in 1982 – and thus at a time when there was already a larger accelerator than DORIS in Hamburg. Nevertheless you decided to install a new detector at an old machine. What was behind this decision?

Walter Schmidt-Parzefall: Around 1977, most physicists here at DESY already believed that the DORIS accelerator had reached its full potential and so were concentrating on the construction of a new, larger storage ring called PETRA. But Herwig Schopper, who was DESY Director at that time, had the feeling that there was still something left in DORIS. He first asked the established researchers in Hamburg whether one of them would like to stay at the old, small machine and continue conducting experiments there. He was turned down by all of these “stars”, however, who instead preferred to work on PETRA, the new, large machine. Schopper then remembered his PhD student – and that happened to be me. He offered me a position as head of department if I would come to Hamburg and work on the small machine. I saw this as a great opportunity and agreed. I had barely arrived when there was a tremendous stroke of luck: a new quark called the bottom quark was unexpectedly discovered in the USA. And this new quark was an ideal research subject for DORIS. Schopper’s feeling that the old machine still had something to offer proved to be intuitively astute.
With the PETRA storage ring, DESY finally gained a top ranking in international particle research.

**ON A COLLISION COURSE**
Full speed ahead – on a collision course

With the PETRA storage ring, DESY finally gained a top ranking in international particle research

In 1974 the DORIS storage ring was not even completed yet, but the physicists were nonetheless already making plans for its successor. Its name: the Positron-Electron Tandem Ring Accelerator PETRA. Like DORIS, its job was to fire electrons at their antiparticles, positrons. But PETRA was much bigger: with its circumference of 2.3 kilometres, it just managed to fit into the dimensions of the DESY premises – the world’s largest storage ring at that time.

There were good reasons for the expansion: the larger the ring, the gentler is the curvature of the path along which the electrons and positrons must travel. And the more gentle the curve through which a particle flies at nearly the speed of light, the lower the energy losses due to radiation that it suffers. It is a bit like driving a car: you can manage a gently curving stretch of motorway nearly at full speed, but a driver has to use a lot of braking power in order not to fly out of a sharp bend in the Alps. In other words, the car loses more kinetic energy in the sharp Alpine bend than in the gentle bend on the motorway.

Tight bends: nice to look at, but a challenge for fast particles
For a particle accelerator this means that the particles in a large ring can be accelerated to higher energies and then collide with far more impact than in a small one. This results in higher collision energy, and thus a better chance of producing new, formerly unknown elementary particles. To put it in numbers, PETRA achieved a collision energy of 38 GeV, and later even 47 GeV, or about four to five times that of the previous generation of accelerators.

Despite its dimensions, PETRA was relatively affordable, since a lot of the needed infrastructure was already available in Hamburg. It was possible, for example, to pre-accelerate the particles in the synchrotron. The result was like starting out in a car in first and second gears before cruising in high gear at top speed onto the motorway. And because all the development work was carried out by the DESY experts themselves, companies without specialist expertise in accelerators were able to produce some components. The plates for the magnets’ iron yoke, to name just one thing, were made by a company that normally produced refrigerators.

PETRA was approved in October 1975, at construction costs of about 100 million deutschmarks. Less than three years later, in July 1978, the first electrons were circling in the ring. The fast construction time may well have been a new record. Not only did the PETRA construction engineers finish a full year ahead of schedule, but the final cost was 20 million deutschmarks less than that anticipated in the original budget. That put DESY ahead of competitors worldwide: the PEP storage ring in California was not completed until two years later.
In parallel to the construction of the accelerator, several hundred physicists assembled in five teams to record the particle collisions by means of gigantic detectors distributed around the ring. Only a small number of these researchers were DESY employees. Most of them were from institutes and universities from all over Germany and around the world. A new aspect was that each team was entirely responsible for the construction, operation and financing of its detector. In return, though, they were largely free to act independently. This concept has meanwhile become a common approach in many other projects in the field of particle physics.

The initial measurements began in October 1978. One year later, PETRA made its most important discovery: the physicists detected the gluon – the “glue” particle that transmits the strong force between the quarks and holds them together. With this achievement, DESY finally established itself as a world-class research institute. Along with the big US labs and CERN in Geneva, it has since been a leading centre for particle physics research.
What is a particle detector?

A detector serves as a precision camera for taking pictures of particles. The particles from the accelerator collide in it, moving at nearly the speed of light, and the detector records exactly what happens. The collision creates new, in some cases heavy particles. Examples include certain types of quark or their “adhesive” particles, the gluons. But the detector is not able to verify these exotic particles directly, since they only “live” for a split second and quickly decay into other, lighter particles that dart away in different directions and leave their traces in the detector.

The physicists must measure these traces with maximum precision. That is the only way they can reconstruct which exotic particles were directly created during the collision — a painstaking way to gather evidence. To achieve the greatest possible precision when detecting the particles that fly away from the point of collision, the detector is equipped with various “sense organs”:

In the centre there are vertex detectors and/or tracking chambers. Both follow the flight paths of the particles that shoot through the detector after a collision. The electromagnetic calorimeter measures the energy of the rather light particles that were created after the collision. These include electrons and particles of light (photons). The hadronic calorimeter, on the other hand, records the energy of the heavier particles (hadrons). Large magnetic coils immerse the centre of the detector in a strong magnetic field, which bends the flight paths of the particles that fly away, thus making it possible to determine important values such as charge and momentum. In the outermost position are the muon chambers. Muons are the heavy relatives of the electrons. They fly the farthest in the detector and are therefore only snapped up by the exterior layer.

Particle detectors — measuring instruments as high as a house — are packed with sensors and electronics. Over the decades they have become larger and larger, and also more sensitive: a PETRA detector like JADE was about five metres high and weighed 1200 tonnes. Today’s biggest detectors stand at the CERN particle research centre in Geneva, Switzerland; at a height of 25 metres they are as big as an office building and weigh up to 12,500 tonnes.
In 1986, when the experimentation programme had become exhausted and the detectors shut down, the experts were unanimous about one thing: PETRA played a crucial role in establishing the still-young Standard Model of particle physics, which maintains that the matter in our world is essentially composed of the tiniest elementary building blocks – of quarks and electrons.

But that was far from the end for PETRA. Right after the detectors were shut down, the ring was modified into PETRA II – a pre-accelerator for HERA, which remains the biggest machine at DESY to this day. And following further extensive modification, the ring is now in its third incarnation: from 2009 PETRA III will serve as the world’s brightest X-ray source of its kind. Its tremendous brilliance will attract researchers from all over the world to Hamburg.
Tracking down “glue” particles

Paul Söding took part in one of the most important discoveries at PETRA.

The PETRA accelerator was started up in July 1978, one year earlier than originally planned — and thus almost two years before a competing project in California. Isn’t that unusual for a major scientific project?

Paul Söding: Definitely. The reason was that we had Gustav-Adolf Voss, who probably was the best construction engineer for accelerators at that time. He had an extraordinarily efficient way of leading his team — everyone tackled their work with tremendous energy. And PETRA was not only completed ahead of schedule; it also cost nearly 20 million deutschmarks less than had been estimated.

How did it feel to be able to conduct experiments with what was at that time the world’s largest, most high-performance electron ring?

It was wonderful. We expected to make many discoveries, and that really inspired us. We especially hoped to find the top quark, the heaviest of the six quarks. Back then nobody expected that the top quark was in reality much too heavy to be detected with PETRA. It wasn’t found until 1995, at a much bigger accelerator in the USA.

But you and your colleagues did make a different important discovery: the gluon, a “glue particle” that holds the quarks together. How did you find it? Did it suddenly show itself one night in signals recorded by the instruments?

No, it was a much slower process. Each collision in the PETRA ring usually creates a large number of particles — from ten to 15. We had to use a detector to measure their flight paths with maximum accuracy, in order to then evaluate and analyze them. But there was too much data, so we had to write a software program, which automatically performed the analyses. All that work was a long and laborious process. And it took months until there were no remaining doubts that we had really found the gluon.
At the time there were five teams of researchers searching for the gluon with their detectors. Wasn’t there quite a competitive atmosphere? Naturally it was a race. I was working on the TASSO team. We were well prepared, and when PETRA was started up, our hardware and software was ready. That gave us something of a head start over the other teams. The gluon revealed itself through what is called a three-jet event. And thanks to the foresighted work of our colleague Sau Lan Wu, we had a software that was able to recognize such events rather quickly.

Can you tell us more about your team’s work?
Each of the five teams consisted of between 50 and 100 scientists. The accelerator was running around the clock, so we worked day and night. We all had our hands full, and the equipment was complex. The team members engaged in many discussions, and we didn’t always agree with one another. But the work is what united us. And it was clear to us that we would be successful only by working together as a team.

Many experts think the discovery of the gluon deserves a Nobel Prize. Why then has it not been honoured with the prize – at least not yet? A Nobel Prize in Physics would certainly be great for DESY. After all, the prize is tremendously prestigious. There is, however, a problem with the discovery of the gluon: who should be the prizewinner? Ultimately it wasn’t the work of two or three physicists but rather a team effort by many people whose work was crucial to the discovery. Maybe that is why there hasn’t been further movement concerning the Nobel Prize in this regard.
A (professional) life with PETRA

Klaus Balewski is playing a key role in upgrading the accelerator

“This is a quadrupole magnet, a kind of magnetic lens for electrons,” says Klaus Balewski, standing next to one of the red-painted blocks of metal found at intervals of a few metres in the tunnel. Then the physicist points out the stainless steel pipes, with nearly the thickness of a human arm, that pass through the centre of the magnets. “The electron beam flies through the pipe. And the X-ray beam runs through the pipe next to it,” he says, raising his voice to be heard amid the high-pitched, whistling noise made by the magnets’ water cooling system.

The components Balewski is referring to are brand new – even though they are parts of an accelerator that has been around for a few decades. Balewski is deputy project leader of PETRA III, one of the current DESY projects. His team is turning a former particle physics accelerator into one of the world’s brightest X-ray sources.

For that, the physicists had to entirely rebuild one eighth of the 2.3-kilometre-long ring and install a total of 14 special magnets called undulators. The undulators cause the electrons from the accelerator to wiggle, which causes the particles to emit intense X-ray light. The experts’ challenge is to work at an extremely high level of precision and to align the undulators in their positions with a margin of error of less than one millimetre.

“If you draw an analogy to the automotive industry, we aren’t building an ordinary compact car here; we’re working on next season’s Formula 1 race car,” explains Balewski. It is the art of engineering at the very limit of what is possible. “Sometimes it’s aggravating and stressful. But that’s part of the work,” he says, while seeming quite relaxed.

PETRA III was started up in 2009 – DESY’s anniversary year. But this does not mean Balewski’s job as deputy project leader is finished. “I am sure that PETRA III will be keeping me busy for a while – at least until the end of 2010,” says the physicist. “And there are already ideas for further expanding the machine.” So it may well turn out that Klaus Balewski will spend a few more years of his professional life with PETRA. And it is hard not to have the feeling that he likes the prospect.

Balewski was involved with PETRA even back when he was still working on his PhD, in the mid-1980s – at that time with its first, original version. Then the ring was upgraded to PETRA II, a pre-accelerator for the much larger HERA machine.

“I was very active in the operation of PETRA II,” Balewski says. “And since 2001 I have been working on how to make a light source out of PETRA II.”
The world’s longest concrete slab: for PETRA’s third life as a light source one eighth of the ring was completely rebuilt.
FROM BUNKER TO MAJOR LABORATORY
From bunker to major laboratory

Using a particle accelerator as an X-ray source

In the 1960s and 1970s, Hamburg gradually developed into a major centre for particle physics. Hardly anyone knew at the time, however, that DESY would eventually establish a second pillar in the area of synchrotron radiation. It turns out that accelerators are not only useful as tools for particle researchers, but also as powerful X-ray and UV “lamps”. With its Hamburg synchrotron radiation laboratory HASYLAB, DESY today is one of the world’s top addresses for using X-rays in research. The ultra-powerful light sources are benefiting thousands of scientists, including physicists, chemists, materials scientists, biologists, medical experts and geologists.

The story begins before DESY was even founded. It was back in 1947 that the US technician Floyd Haber first noticed a blinding light produced by an electron accelerator operated by his employer General Electric. As the accelerator was a synchrotron, the light was henceforth known as synchrotron radiation. When the particle physicists at DESY built their first synchrotron in the early 1960s, they were annoyed by the blinding light, because synchrotron radiation limits the maximum amount of energy that an accelerator can reach.
However, the supposedly disruptive effect was also useful – admittedly not in particle physics, but in other disciplines such as materials science. Scientists at DESY began to look into this matter before the first accelerator, the synchrotron, was even finished. The driving force behind these considerations was the Research Director at the time, Peter Stähelin, who felt that synchrotron radiation could open up nearly limitless opportunities for experimentation. He therefore commissioned the young physicist Ruprecht Haensel to study the possibilities of the new light source in his PhD thesis. The associated project would be housed in an underground bunker next to the accelerator.

After the first experiments were carried out in 1966, it became clear that DESY was on the right track with respect to synchrotron radiation. However, it proved difficult to get other scientists in Germany interested in the new method. Many researchers did not recognize the possibilities of the new light source or were not willing to work in Hamburg before the first scientific papers were published of the results. When these were released, it was evident that the X-rays from the accelerator are far brighter than those from a conventional X-ray tube. The accelerator therefore made it possible to conduct far more precise analyses of a diverse range of different materials, from metals and plastics to biological samples. The researchers’ interest grew as a result and the bunker became too small for the facility. A second storey was therefore added, followed later on by a second measurement bunker. In 1974, the DORIS storage ring went into operation. Because it stored the electrons for hours on end, it provided a much more stable and non-fluctuating X-ray beam than the synchrotron. A separate lab was then set up for the users of synchrotron radiation. It measured only 120 square metres, however, and soon proved to be too small to handle the huge demand that had developed in just a few years.
Van Gogh under the X-ray microscope

The painting shows a flowering, green summer meadow. It is a genuine van Gogh, painted in 1887, three years before the death of the eccentric genius. However, studies recently revealed that “Grasgrond”, as the masterwork is titled, hides another, older painting by van Gogh. It is a portrait of a peasant woman, with a dark, somewhat coarse appearance. The spectacular discovery was made in 2008 at HASYLAB. A special X-ray method made the picture, which the artist had painted over himself, visible in great detail.

Some time previously, a team of Belgian and Dutch art historians had discovered the contours of a head underneath the painting’s surface. However, the experts wanted to find out what the head actually looks like, which is why they took the valuable painting to Hamburg. Measurements then commenced at the DORIS accelerator, using a special method known as micro-fluorescence analysis. In this process, the X-ray beam scans each point of the painting in a completely non-destructive manner. Each of the chemical elements in the paint responds to this X-ray “stimulus” in a distinctive way, making even pigments that are found in the painting only in trace amounts visible.

Two elements are particularly prevalent: antimony and mercury. They are mainly found in the portrait that was painted over and are less common in the covering picture of the summer meadow. Although the antimony pigment was only measurable in tiny concentrations, the signal of the pigment revealed the light coloured areas of the face, such as the nose and chin. Van Gogh used mercury compound pigments, such as vermilion, to paint the peasant woman’s red lips and ruddy cheeks. When the analyses were concluded, the art experts were thrilled with the result, as it showed not a rough sketch, but a reconstruction of an actual, detailed and colourful portrait of a country woman.

It is now known that van Gogh painted this portrait sometime between 1884 and 1885. However, the art historians think that only two years later the master artist may have considered his painting to be so old fashioned that he replaced it with the expressive representation of a meadow scene.
In 1978, the researchers were promised a substantially larger laboratory, the Hamburg synchrotron radiation lab HASYLAB. It was completed in 1981 along with a large experimental hall. A total of 15 experimental stations were now available for use, and this number was later raised to 30. The European Molecular Biology Laboratory EMBL installed an outstation at DORIS in order to analyse biomolecules in detail. It was joined soon after by working groups from the Max Planck Society, who set up a permanent outstation.

The next big step came in 1991, when DORIS II was upgraded to DORIS III to generate even more light with the accelerator. One of the two straight segments received a “bulge”, in which seven additional special magnets known as wigglers and undulators were installed. The magnets produce particularly intense X-rays, without which certain experiments would not be possible.

Today, more than 2000 researchers come to Hamburg from over 35 countries each year to conduct experiments at HASYLAB. The range of experiments is extremely broad, as DORIS’ powerful radiation enables the scientists to look deep into the structure of matter. For example, the scientists develop effective catalytic converters for a cleaner environment, create innovative active substances for medical use, devise more precise analysis methods for detecting pollutants and make new lightweight yet stable materials for a mobile society.

What is synchrotron radiation?

Synchrotron radiation is created when particles such as electrons move along an accelerator ring at nearly the speed of light. Every time that the electrons get directed along the curve by the deflecting magnets, they lose some of their energy by emitting an extremely intense beam of light. The effect is in principle comparable to that of a radio tower, in which electrons are moved back and forth in order to generate radio waves. However, the electrons in the storage ring have much more energy than those in a radio tower, which is why they also create more high-energy radiation. It does not consist of radio waves, but of a broad spectrum, ranging from infrared light to hard X-rays.

Even more effective than deflecting magnets are special magnets known as wigglers and undulators. A wiggler is used in storage rings and consists of a series of alternating pairs of magnets extending over several metres. This magnetic “racetrack” forces the superfast electrons to speed along a narrow zigzag channel. On account of the large number of successive magnetic poles the electrons emit a much more intense beam of light than that produced with a single deflecting magnet. Use of a wiggler generates synchrotron radiation up to 100 times as intense as that produced with deflecting magnets. In a certain mode of operation, the intensity at specific wavelengths can even be 1000 times higher because the wave trains reinforce one another. As a result, the wiggler is transformed into an undulator.

For scientists, synchrotron radiation is a very welcome research tool that is particularly useful when working with X-rays. This is because the X-rays produced by the accelerator are up to one million times brighter than those from X-ray tubes in doctors’ surgeries. In addition, synchrotron radiation is almost as concentrated as a laser beam. Scientists of almost all disciplines use synchrotron radiation to study the most diverse materials with atomic precision. These materials range from metals and semiconductors to plastics and protein molecules.

Experimental huts at HASYLAB
In February 1962, physicist Ruprecht Haensel, who was 26 at the time, was asked to find out for his PhD thesis whether something sensible could be done with a “by-product” that the first DESY accelerator would begin to generate in a few years time: synchrotron radiation. Haensel was charged with building a beam pipe through which the radiation could be channelled from the accelerator to an experimental station that would be housed in a kind of bunker next to the synchrotron.

For Haensel this meant conducting a lot of pioneering work. “At the time, there was no lab in the world that systematically worked with synchrotron radiation and that could serve us as a model,” he says. “We were therefore the first people who wanted to systematically exploit the new type of radiation.”

Haensel therefore waded through the specialist literature and also learned about vacuum technology because the concentrated radiation had to be channelled to the experimental station through a beam pipe out of which all the air had been pumped. “From time to time, somebody would accidentally open a valve, causing an implosion that ventilated the entire ring.” Once, after a torrential summer rain, the researchers even had to bail out the bunker by hand. “We took off our trousers and stood there only in our underpants,” says Haensel. “It certainly made a very masculine impression.”

However, such setbacks could not discourage Haensel. In 1965, he was able to attain an important milestone after the synchrotron had gone into operation: “I could see the light in the ring in a mirror. It was a dazzling light – a really exciting moment.” The event allowed Haensel to demonstrate that the synchrotron radiation had the theoretically expected properties in the X-ray range, and thus enabled him to obtain his PhD in 1966. The results showed that the radiation generated by the particle accelerator is several orders of magnitude more powerful than that produced by conventional X-ray tubes, such as those found in doctors’ surgeries.

Despite these insights, “particle physics experiments always had priority, so our work had to take a back seat,” says Haensel. “Most particle physicists at DESY considered our work to be a kind of waste recycling and affectionately called us parasites.” The first experiments were carried out under the most primitive conditions imaginable. The researchers crouched behind a protective wall and held two wires. One of the wires was used to pull the sample into the beam, while the other was employed to pull the sample out again.

“We initially were just happy to take measurements even though I think the first results were just pure nonsense,” says Haensel. The tests then began to bear fruit in the measurement of certain metals, for example. Academic papers followed in quick succession, and the success rewarded the researchers for their efforts and many nights of work. “Although we knew at the time that we had hit on something very interesting, we could have never guessed that it would take off in the way it later did,” says Haensel.
Scrubbing for science:
pioneering work in the HASYLAB bunker.
The lab is as big as a gymnasium, and is chock-a-block with every kind of physics instrument imaginable: vacuum chambers, cables, cabinets full of special electronics, and long beam pipes wrapped in aluminium foil. Pumps hiss, the ventilation system whirs, and now and then a machine voice announces which of the lab’s 36 experimental stations is currently in use.

Robert Feidenhans’l is working at a computer, not far from a metal hut bearing yellow markings. For a few days, the physics professor from the Niels Bohr Institute in Copenhagen is working at HASYLAB in order to subject his samples to DORIS’ intense X-ray beam. The samples consist of tiny silicon plates with nanometre-sized surface structures – fundamental research for nanotechnology.

Feidenhans’l was one of the first researchers to work at HASYLAB. In 1981, he first got to know the lab as a summer student when he did an internship there during his summer break. Later on, when he was a PhD student, he set up the BW2 experimental station. “I still know it inside out,” he says. Feidenhans’l and his team come to Hamburg three or four times every year in order to make measurements at BW2.

When asked how such measurements are done, Feidenhans’l replies that “we first have to adjust the instrument and the sample. It’s almost the most important thing we have to do – in fact, a physicist who can’t properly adjust the system will make incorrect or imprecise measurements!” For this adjustment work, the researchers push various shutters, mountings and adjusting screws back and forth until the hair-thin X-ray beam optimally strikes the sample. The detector, which more or less serves as an X-ray camera, must also be adjusted in such a way that it records the signals as accurately as possible. “This procedure mostly takes up half a day and therefore requires a lot of patience,” explains Feidenhans’l.

Once this task is completed, the measurements can finally begin. They take place in a screened-off area in a special hut with lead walls. “Once the beam enters the hut, nobody is allowed in,” he says. The experiment is controlled on a computer outside the hut. Inside it, the X-ray beam is reflected in specific directions after striking the silicon plate sample. “We use the detector to determine where the X-rays have been reflected to,” says Feidenhans’l. “We analyse where and how strong these reflections are.” The sample and the detector are systematically rotated in order to create a complete series of measurements. The resulting data can be used to find out in detail how the silicon plate’s surface is structured.

Because the storage ring runs day and night, the physicists have to work in shifts. “The young researchers always have to do the night shifts of course,” jokes Feidenhans’l. Should there be nothing to do for a while, the scientists can divert themselves in a non-academic manner with a game of table football. “Most of the time, however, we use such lulls to begin evaluating the measurement data,” he says. “It allows us to determine if a sensible measurement has been made or if the sample was incorrectly adjusted or is unsuitable.”

And what does the future hold in store? Feidenhans’l replies with a smile: “I’ve seen the new PETRA III experimental hall and I’m already looking forward to doing measurements there!” Feidenhans’l’s sentiments are understandable, since the X-ray beams from PETRA will make it possible to scrutinize the Danish nanocrystals far more precisely than was previously the case.
06: HERA

With HERA, DESY built its biggest accelerator

THE GIANT OF BAHRENFELD
The giant of Bahrenfeld

With HERA, DESY built its biggest accelerator

On 30 June 2007, a Saturday, more than 100 physicists crowded into DESY’s accelerator control room. Then, at precisely 11:30 p.m., they all called out the countdown together. When they reached “zero” there was a moment of perplexed, uneasy silence before everyone broke out in a round of heartfelt applause – for HERA, the largest particle accelerator that DESY had ever built. On this evening in the summer of 2007 the 6.3-kilometre-long ring was shut down with the push of a button after being in operation for 15 years.

The HERA story began in the late 1970s. The PETRA ring had just been put into operation, and the people in charge of DESY were already considering what shape a successor project might take. One of the researchers, Björn Wiik, advocated a bold idea. He proposed an entirely new and unprecedented type of storage ring: an accelerator that would shoot electrons and hydrogen nuclei, that is protons, at each other. According to the calculations, such a machine would serve as an extremely high-performance microscope for the proton. It would thus become possible to investigate these important particles of matter in greater detail than ever before – thus complementing other storage rings in very valuable ways.
Frozen magnets

Hydrogen nuclei (protons) can be accelerated to much higher energies than electrons because their losses through synchrotron radiation are smaller. They are much heavier than electrons. As a result, a proton ring requires much more powerful magnets than an electron ring in order to hold the particles on their course. The best and most effective technique for building such superstrong electromagnets uses superconductors. Superconducting materials lose their electrical resistance and conduct current entirely without loss – provided they are cooled to extremely cold temperatures of approximately minus 269 degrees Celsius, or about four degrees above absolute zero.

The construction of HERA’s superconducting proton ring was a formidable challenge, as the HERA engineers had to develop magnetic coils based on a very large number of special cables made of a niobium-titanium alloy, which were many, many metres long. These coils had to be shaped with extraordinary precision and remain fixed in their positions to within one fiftieth of a millimetre.

That’s anything but an easy assignment, given the enormous forces at work in such a magnet: during operation each metre of coil had to withstand about 100 tonnes. HERA required a total of 750 superconducting magnets, most of which were nine metres long and weighed ten tonnes. In a major challenge for the manufacturing sector, the magnets were serial-produced by two companies, based in Italy and Germany.

Equally demanding were the cryogenics, since the entire 6.3-kilometre-long proton ring had to be cooled to minus 269 degrees Celsius using liquid helium. To this end, DESY commissioned the Sulzer company to construct Europe’s biggest “refrigerator” at the time, which was so big that it required its own hall. With a throughput of 15 tonnes of liquid helium, it delivered more than ten times the performance offered by any other comparable refrigeration plant in Europe.
By causing electrons and protons to collide at high energies, the HERA accelerator functioned as a super microscope for protons (hydrogen nuclei). Protons consist of quarks. During the collisions, the electrons served as probes that analysed the interaction of the quarks, enabling the physicists to study the quark structure inside the proton in unprecedented detail.

Over the years the H1 and ZEUS experiments at HERA revealed that the proton consists not only of three quarks but of a veritable swarm of quarks, a "sea" of particles, most of them very fleeting and short-lived. That means the structure of the hydrogen nucleus is far more complex than expected. The measurements also suggest that quarks are actually elementary and not made up of smaller components – another important finding. With HERA it was even possible to estimate the maximum dimensions of a quark, which is smaller than one one-thousandth of the diameter of the proton.

HERA also played a key role in a Nobel Prize: in 2004, American physicists David Gross, David Politzer and Frank Wilczek were honoured for their theoretical calculations of the strong force at work between the quarks. HERA had impressively confirmed their calculations.

HERMES, a HERA detector built in the 1990s, also brought interesting findings to light. It took on a problem that the particle researchers call "spin crisis". The spin of an elementary particle is best visualised as its intrinsic angular momentum. The physicists had known for a long time that the spin of the proton has the value of 1/2. But the question was: how does this value come about? One potential answer is: you simply add the spins of the three quarks that make up the proton. The addition results in a value that is much too small, however. HERMES provided clear indications of one of the probable causes of a large part of the remaining spin: the movements the quarks perform within the proton.

Many of the insights gained with HERA are now standard material for physics textbooks and belong to our fundamental knowledge of how our world is put together. During its 15 years of service the Hamburg particle accelerator did not, however, deliver any sensational physics discoveries – which was a bit disappointing for the researchers. The scientists had hoped, for example, that individual electrons would stay stuck to the quarks during collisions and thus form an entirely new particle. The existence of such a leptoquark would have rocked the foundations of the field of particle physics and might very well have earned the HERA researchers a Nobel Prize. But as at the world’s other big accelerators, the search for such exotic particles at HERA was not successful.
One thing quickly became clear: if the aim was really to conduct top-class research, the dimensions of this Hadron-Electron Ring Accelerator, or HERA for short, would be too big for the DESY campus. In concrete terms, the plan called for the new machine, which would consist of two vacuum pipes, one superimposed on the other, to be located in an underground, 6.3-kilometre-long ring-shaped tunnel. Beginning from the DESY premises, the ring was to pass at depths ranging from ten to 20 metres beneath Hamburg’s largest park, “Volkspark”, and a racing track, but also under a commercial district and several dozen houses. It was a daring plan, since nowhere in the world had anyone ventured at that time to build an accelerator under a city’s residential neighbourhoods.

And the technical challenges seemed enormous. The fast protons, for instance, were to be held on their circling path by means of superconducting magnets – a very challenging technology. Costs were another obstacle: the total price of the accelerator would be around one billion deutschmarks. To handle such a megaproject, the physicists led by Björn Wiik and Volker Soergel, the DESY Director at that time, had to attract researchers and institutes from abroad to HERA, and to secure their practical and financial support.

HERA was the biggest and most difficult undertaking that DESY had ever attempted. No one had ever built such a storage ring; the team in Hamburg was moving into completely unknown territory. Many experts and policy-makers were therefore sceptical that the concept could work. But the physicists at DESY were able to convince them. For one thing they presented a sound plan showing how to ensure an effective design of the superconducting magnets and how to have them built by manufacturing partners in industry. And they also succeeded in bringing to HERA renowned institutes from abroad, for example, from France, the United Kingdom, Italy, Canada, Israel, the Netherlands and the United States. These partners sent people and built important components for the accelerator. Italy alone supplied about half of the 750 superconducting magnets – a key contribution.
Hunting particles with ZEUS

The Oxford physicist Brian Foster was experimenting right from the start at the HERA ring. From 1999 to 2004 he served as the spokesman of ZEUS, a multinational team of about 450 physicists.

What motivated you to join the ZEUS project in the early 1980s?

Brian Foster: Starting in 1978 I had been working on TASSO, one of the detectors at the PETRA accelerator. Many of my TASSO colleagues then committed themselves to ZEUS. So it seemed right for me to also take part in experiments at the new machine, given that it promised to provide very interesting findings. Building a detector for HERA proved to be very challenging, however. Compared to the detectors at PETRA, it had to be capable of collecting and processing much more data.

The ZEUS team comprised about 450 physicists from many different countries. Did the team effort always go smoothly?

Well, there were differences of opinion now and then about engineering details related to the detector’s design. And sometimes these differences went so far that several researchers left the project. But that can hardly be avoided whenever you have such a big team. On the whole, though, there was excellent teamwork. The disputed points were usually resolved in discussions.

Including interruptions, ZEUS ran for 15 years, and you were involved for the whole time. What was your most exciting experience during those years?

I still remember very well when HERA went into operation and we started up our detector. As the first particles were ready to collide, we were staring transfixed at the monitor. We had no idea what to really expect and were very pleased when we saw clear signs of particle collisions rather than noise. Then we knew that ZEUS really worked!

Then, a few years later, it looked like ZEUS had discovered an entirely new and exotic particle – the leptoquark. This discovery would have been a sensation, which is why this was a very exciting period at DESY. But about six months later it became clear that it unfortunately was just a statistical quirk, not a discovery.

What did you consider the most important finding of the HERA experiments?

HERA determined how the proton is structured in detail, and how the strong nuclear force determines this structure. This knowledge will be found in every textbook published in the coming decades. And I don’t believe we will see some fundamentally new development in this area in the foreseeable future.
In April 1984 the “green light” was given by German Research Minister Heinz Riesenhuber and Hansjörg Sinn, Hamburg’s Minister of Science at the time. Construction work began just a few days later. After one year the tunnel boring machine went into action – a kind of gigantic “mechanical mole” that burrowed beneath the earth in Hamburg. In parallel, four tremendous underground halls were built at intervals along the ring to house the detectors – massive installations, some as big as a house, jam-packed with electronic measurement equipment and highly sensitive sensors. The first two detectors to be completed, called H1 and ZEUS, were operated and financed by multinational teams consisting of several hundred physicists.

In August 1987 the tunnel boring machine had finished excavating the ring without encountering any major problems. The circle was closed at the point it had begun, with a margin of error of only two centimetres. Then, in November 1990, Research Minister Riesenhuber pushed the red button in front of more than 1000 invited guests. HERA was activated – at least symbolically. Its construction had taken six-and-a-half years. The ambitious time schedule was kept, and the physicists stayed within the budget of roughly 1.2 billion deutschmarks for the accelerator and the detectors. Particularly noteworthy is that although HERA was a German project, foreign partners contributed a total of more than 20 percent of the costs of the accelerator and the detectors, or nearly 300 million deutschmarks in all.

The measurements commenced in June 1992. Initially electrons were fired at protons, and then positrons also were shot at them. In 1998 the physicists succeeded in boosting the energy of the protons from 820 to 920 GeV. And beginning in 2000 they gave HERA an extensive upgrading, which made it possible to more than double the luminosity – the value with which experts measure the particles’ “hit rate”.

HERA ran very reliably for 15 years, delivering a wealth of data. The experiments at Germany’s largest research tool, which has written physics history, ended in the summer of 2007. Until well into the coming decade, the evaluation of the data will be providing unique insights into the inner structure of the proton and the fundamental forces of nature. But the machine wasn’t dismantled. DESY has decommissioned it and taken steps to ensure that nothing rusts. And if someone has a brilliant idea some day, to do something new and exciting with HERA, it won’t be difficult to bring the accelerator back to life.

A toast to a great machine: HERA was switched off in summer 2007.
07: Zeuthen

DESY has a powerful branch location at Zeuthen in eastern Germany
Research by the lake

DESY has a powerful branch location at Zeuthen in eastern Germany.

The location is idyllic, consisting of a lake-front property where hot summer days tempt people to take a dip in the water. What’s more, the site is of historic significance, as the former restaurant and hotel known as “Hankels Ablage” served as the backdrop to many of the key scenes of Theodor Fontane’s famous late-19th-century novel “Irrungen, Wirrungen” (Trials and Tribulations. A Berlin Novel). Today, the site is home to the administrative building of the second DESY facility, which is located in Zeuthen, south east of Berlin.

The institute can look back on a very varied history. Its roots go back to the year 1939, when the German Postal Ministry set up a nuclear physics laboratory in Zeuthen known as the Agency for Special Physical Issues. In the previous year, Otto Hahn had discovered nuclear fission. Among other things, the researchers in Zeuthen therefore wanted to find out whether the “smashing of atoms” could be used as a new source of energy as well as for the creation of bombs with incredible explosive force.

However, the Postal Ministry did not make much progress in this regard. Although it began to build a cyclotron, which was the most advanced type of accelerator available at the time, in Zeuthen, the institute was occupied by Soviet troops in May 1945, shortly before the facility could be completed. The Russians immediately began to disassemble the cyclotron and all other equipment at the site.

In 1950, the newly established German Democratic Republic began to take an interest in nuclear physics, for which it created the Miersdorf Institute at the former site in Zeuthen. The facility was known as Institute X in internal documents, with the letter “X” standing for nuclear physics, research of which was still forbidden to Germany at the time. The new institute’s mission was to create the research basis for nuclear power plants and to manufacture radioactive isotopes for medical use.
Electron brain, electron gun, ice cube

Around 200 people work at DESY in Zeuthen, where research is focused on three areas:

01 Established in 1994, the Centre for Parallel Computing is an internationally renowned computer centre for theoretical particle physics. Using special superfast computers consisting of hundreds of processors, the researchers at the centre can carry out difficult calculations, simulating the complex interaction of quarks, for example. The scientists can then check the accuracy of these computer simulations by means of particle accelerator experiments.

02 The researchers in Zeuthen have also set up a very special test rig known as the Photo Injector Test Facility, or PITZ for short. The facility is used to develop special high-precision “electron guns”. Doing so is a huge technological challenge, since these guns have to generate billions of electrons within a trillionth of a second and combine the particles into a tiny package. But such ultra-precise electron sources are needed for the world’s most powerful X-ray laser: the X-ray free-electron laser European XFEL, which is being built in Hamburg.

03 Astrophysicists from Zeuthen are also extensively involved in a spectacular large-scale experiment at the South Pole known as IceCube. Almost 5000 highly sensitive optical sensors have been suspended on wires several kilometres into the Antarctic ice cap, encompassing a volume of one whole cubic kilometre. Housed in basketball-sized glass spheres, the sensors are designed to detect neutrino signals. Neutrinos are ghostly elementary particles that very rarely interact with normal matter. Scheduled for completion in 2011, IceCube will serve as a neutrino telescope that will observe the phantom particles from the farthest reaches of the universe. The researchers hope to gain completely new insights into extreme cosmic events such as what happens near black holes, how the supernova explosion of a dying giant star unfolds and how cosmic particle accelerators work.
East Germany’s first research reactor went into operation in 1957 in Rossendorf near Dresden. This shifted the focus of nuclear research in East Germany, and the scientists in Zeuthen now turned to particle physics. The institute was now called the Research Centre for the Physics of High Energies before being renamed the Institute for High-Energy Physics (IfH) in 1968.

However, East Germany did not have a large accelerator of its own, which is why the scientists from Zeuthen cooperated with their counterparts from the Joint Institute for Nuclear Research, the Eastern European accelerator centre in Dubna, Russia. In addition, they regularly travelled to the West to take part in experiments at the European particle research centre CERN in Geneva, Switzerland. From 1965 to 1967, the East German physicists even participated in the evaluation of test results obtained with the DESY synchrotron, until the communist government prohibited any further scientific cooperation between the two German countries. Despite these restrictions, CERN enabled the institute in Zeuthen to continue to maintain contact with research teams in Western Europe.

Relations between the East and West Germany improved somewhat in the mid-1980s, leading to an agreement on scientific and cultural cooperation. As a result, the IfH was officially allowed to become involved in the H1 experiment, which was one of the two large particle detectors that were being built at the time for the HERA storage ring.

Then, in November 1989, the Berlin Wall fell. Despite all of the joy about the end of the Cold War, the staff in Zeuthen felt considerable unease about the future. How were things going to continue?, they wondered. East Germany was practically bankrupt and the institute’s survival was totally uncertain. This is when the physicists from Zeuthen were rewarded for having stayed in contact with the particle physics centres in the West despite all of the difficulties they sometimes faced, and for their participation in top international projects such as the L3 detector at CERN.

When independent experts subsequently evaluated the institute’s scientific quality in 1990, their assessment was very positive and they recommended that the facility should be maintained. The institute’s good contacts to DESY in Hamburg also paid off at this time, because the latter had signaled shortly after the Berlin Wall fell that it would be open to a merger. On 11 November 1991, the Federal Republic of Germany signed a state treaty with the states of Brandenburg and Hamburg that incorporated IfH Zeuthen into DESY, which now had two locations, each with a first-rate research profile.
Since when have you been researching and working in Zeuthen?
Thomas Naumann: I started working as a PhD student at the Institute for High-Energy Physics in 1975, when I was 22 years old. Although I came here by pure chance, I was immediately thrilled by the institute’s fantastic atmosphere and the physics being investigated here. The Director at the time, Karl Lanius, had succeeded in creating an environment that was unique in both scientific and political terms. This meant, for example, that the people who advanced in their careers were not necessarily those with high positions in the communist party, as was the case at many other research facilities in East Germany. In a certain sense we were therefore in a very privileged position.

However, the working conditions were probably still not very easy, were they?
We did the best we could under the circumstances. Although only a few of us were allowed to travel to CERN in Geneva to conduct experiments, we were able to contribute a lot to analysing the data. CERN sent us thousands of rolls of film from the particle detector, a bubble chamber. Our high-quality analytical apparatus allowed us to evaluate these recordings in detail. In a sense, these photos brought genuine physics into our lab, almost as if the experiment had been conducted at our own facility. Together with our partners from CERN, we then published the results in international research journals.

When did you first come into contact with DESY?
In 1986, West and East Germany signed an agreement on scientific and cultural cooperation. It enabled us in Zeuthen to take part in the H1 experiment at HERA. Even though I always refused to join the communist party, I was allowed to travel to the West in 1988 in order to work there for several years as a visiting scientist. I was therefore at DESY when the Berlin Wall fell on 9 November 1989. The next morning, all of Hamburg smelled of East German car exhaust fumes, which was of course pretty bizarre!

After the fall of the Wall, it was initially unclear what would happen to the institute in Zeuthen. How did you experience this time of transition?
There was of course a great deal of uncertainty for a time. However, DESY’s Board of Directors headed by Volker Soergel quickly took action to advocate itself on our behalf. We were treated very fairly when we joined DESY – also with respect to issues regarding the East German secret police. Looking back, I have to say that few East German institutes did as well as we did. Of the approximately 60 institutes that belonged to the East German Academy of Sciences, the facility in Zeuthen was the only one to survive practically intact. Even though it may sound somewhat exaggerated, I think the merger of the institutes in Hamburg and Zeuthen was the most successful event in the history of scientific relations between East and West Germany.
The journey to the project site is an adventure in itself, beginning with a 30-hour flight in an airliner to Christchurch, New Zealand. From there, passengers have to travel for eight hours on a military transport plane to McMurdo, a research station on the edge of Antarctica. The next day, the trip continues with a 1500-kilometre flight over ice caps and the Transantarctic Mountains to the Amundsen-Scott Station at the South Pole. Christian Spiering, a DESY researcher from Zeuthen, has completed this arduous trip a total of four times. “When you first get off the plane, you feel like you’re the first man on the moon,” he says. “Wow! This is fantastic, you say. You’re really at the South Pole!”

However, the enthusiasm is quickly followed by altitude sickness, since the South Pole station is located on top of a 3000-metre-thick ice cap that makes the air as thin as it is high up in the mountains. The body has to adjust to this change, and not everyone succeeds in this without suffering complications. Some people suffer from frequent nosebleeds, while a few are in such bad shape that they have to be transported back home. “Thankfully, it only took about two to three days each time before I was sufficiently acclimatized,” says Spiering. “Unfortunately, I sleep really badly down there, but that’s a typical consequence of living at high altitudes.”

The physicist belongs to an international team that has been installing a neutrino telescope at the South Pole since the 1990s. The work involves drilling deep holes into the ice. It is a tough job and has to be carried out in shifts. “We use water heated to 80 degrees Celsius to drill into the ice at two centimetres per second,” explains Spiering. After 40 hours of continuous drilling, the experts achieve their goal of creating a water-filled hole 60 centimetres in diameter and 2.5 kilometres deep in the Antarctic ice cap. “We then insert a steel cable into this hole,” says Spiering. “Glass spheres containing optical sensors hang from these wires at intervals of 17 metres.” Once this “string” with its total of 60 sensor spheres has been lowered into the hole, the researchers let it freeze into the ice.

A difficulty here is that the team only has a limited amount of time available each year for drilling the holes, with the season beginning in early November and ending in mid-February. For these three-and-a-half months – the Antarctic summer – the sun shines 24 hours a day and it is rarely overcast. Temperatures then rise to bearable levels of between minus 35 and minus 25 degrees Celsius. The winters are, on the other hand, passed in continuous darkness, with temperatures plummeting to minus 80 degrees Celsius. The polar station is then only occupied by a few scientists.

The researchers manage to drill up to 19 holes per season. A total of 59 holes have been drilled to date, and when the last of the 86 holes is finally completed in 2011, IceCube will be finished. “We generally work more than 12 hours a day down there,” says Spiering. “After all, there is not much else you can do.” However, the station is equipped with a library and a video archive, and the scientists can also work out in a gym. And the really tough ones can go sweat in the sauna, after which they get to cool off quickly in the Antarctic ice.

The researchers have registered more than 10000 neutrinos so far, although they still can’t definitely say whether any of them are of extraterrestrial origin. Measurements of such neutrinos would solve one of the most exciting questions of astrophysics: how do the cosmic particle catapults work that accelerate nuclear particles to a million times the beam energy of the Large Hadron Collider LHC in Geneva? Cosmic particles were first discovered in 1912 by the Austrian physicist Viktor Hess. Spiering’s hope is that “IceCube will solve the mystery before the centenary of Hess’ discovery!”
08: FLASH

FLASH generates unique radiation for research

WORLD RECORD LASER IN HAMBURG
World record laser in Hamburg

FLASH generates unique radiation for research

At first, the researchers thought the machine was malfunctioning. But an hour later the members of the small international research team at DESY were beside themselves with enthusiasm. On the evening of 22 February and during the early hours of the morning of 23 February 2000, the physicists had optimized the settings of the control computers in a container crammed full of monitors and electronic consoles, as they always do. Suddenly an intensity sensor had registered a value that exceeded the normal level by a factor of 20.

After a few minutes of bewilderment, the scientists realized what they had achieved. Their special laser, which was based on a 100-metre-long accelerator and had been in construction for years, actually worked! It was generating laser flashes with a wavelength of only 110 nanometres (billionths of a metre) one after the other, as if from an assembly line. Experts in the field call these flashes vacuum ultraviolet radiation, or VUV for short. This was a world record, as other devices had previously only achieved wavelengths of 226 nanometres.

The record-setting laser at DESY is one example of a still-new type of research instrument that is called a free-electron laser, or FEL for short. The basic idea was born in the USA in the 1970s. The principle behind it is that tiny electron bunches travelling at almost the speed of light are brought to high energies by a linear accelerator. Next, the electrons race through a series of undulators consisting of many pairs of magnets arranged in a series, which literally force the electrons to move along a slalom course within this magnetic field.
This is where the key process takes place: during the slalom, the electrons lose energy in the form of light, which is amplified by a sophisticated process to form extremely short laser flashes. These flashes are extremely intense, and their wavelength, or “colour”, can be adjusted relatively smoothly across a wide range of values. These two qualities distinguish them from conventional lasers, whose adjustability is limited because they generally radiate only in definite colours, depending on the material used to amplify the light.

The first FEL prototypes, which were created in the 1970s and 1980s, functioned only at relatively long wavelengths. That is why the researchers at DESY wondered in the early 1990s whether they couldn’t build an FEL that generates short-wavelength radiation – that is, VUV or XUV (extreme ultraviolet) or even soft X-ray radiation. Such a laser would offer them completely new insights into the depths of living cells, molecules and materials. Conventional lasers do not function within this range of short-wavelength radiation.
The new device would have several advantages compared to storage rings like DORIS. The concentrated flashes would be several magnitudes more intense than the synchrotron radiation from a storage ring. In addition, the flashes, which would last between 10 and 50 femtoseconds (quadrillionths of a second), would be a thousand times shorter and would therefore enable analyses of very fast processes.

On account of these and other considerations, DESY decided in 1994 to collaborate with more than 50 institutes in 13 countries to build a pilot facility called the TESLA Test Facility TTF. It uses a 100-metre-long linear accelerator built in an innovative superconducting accelerator concept called TESLA technology. The plan was to test this technology extensively using the TTF. One objective was to see whether it could be used for a planned gigantic linear accelerator for particle physics; another was to use it as the basis of a VUV laser.

On that February night in 2000, the researchers succeeded in proving that the principle of the free-electron laser also works for VUV radiation. In the following years, the first research groups began to conduct experiments with the new light source. Starting in 2003, the machine was expanded: in order to create even shorter wavelengths, the researchers lengthened the accelerator from 100 to a total of 260 metres and built an experimental hall with five measuring stations at one end. In 2005, FLASH – the Free-Electron LASer in Hamburg – was finished. It promptly set several world records. FLASH first created a wavelength of 13 nanometres; later it even went down to 6.5 nanometres. To the experts, wavelengths that are this short are no longer in the category of VUV or XUV radiation; instead, they are referred to as soft X-ray radiation.

An unfulfilled dream
DESY physicists planned to realize the 30-kilometre-long TESLA facility in Hamburg

The DESY physicists and engineers who were working with international partners in the 1990s to develop the superconducting accelerator technology had a very ambitious facility in mind: TESLA, a linear accelerator that would be approximately 30 kilometres long. TESLA was to fire electrons and positrons at each other at energies that had never been reached before, in order to generate completely new types of elementary particles. The researchers would then closely examine these as yet undiscovered particles, like the Higgs boson or so-called SUSY particles.

At the same time, TESLA was going to be an extremely strong X-ray laser to “illuminate” substances such as nanomaterials and protein molecules with a precision that had previously been unattainable. The intriguing thing about this concept was that a single machine would be killing two birds with one stone. For particle physics, TESLA would have been the best electron accelerator of all time; for materials researchers, chemists and biologists, it would have been the world’s most powerful X-ray laser.
The problem was that the construction of TESLA would have cost several billion euros, and Germany as the host country would have had to cover approximately half of the cost. This seemed too expensive for the German Ministry of Education and Research, especially since there were two competing projects in Japan and the USA. For this reason, in 2003 the ministry postponed the plans for TESLA until further notice, although it did not cancel them altogether. The ministry urged particle physicists worldwide to agree on a single technology that could then be used to build a future linear collider.

Nonetheless, the work done on the project in Germany up to that time had not been in vain. For one thing, at the same time the ministry set the course for the construction of the European XFEL X-ray laser – a facility more than three kilometres long based on the superconducting TESLA technology. It is currently being built in Hamburg. Moreover, in 2004 the global particle physics community decided to also equip its next major project, the 30-kilometre-long International Linear Collider ILC, with superconducting accelerator beam pipes. This was a major triumph for the researchers in Hamburg. Even though it is still not clear whether – and, above all, where – the ILC will be built, it will impressively turn the TESLA plans into reality.

Every individual light pulse from FLASH has a power of up to five gigawatts – that’s approximately 1000 times greater than that of comparable lasers. Today the experts are able to focus this power into a tiny area with a diameter of one micrometre. In order to do that, the researchers must have extremely tight control over their facility. For example, as the electron bunches pursue their zigzag course through the undulator they must not deviate more than one hundredth of a millimetre from their assigned route. Even the smallest disturbance may be sufficient to throw the laser off course. For example, the FLASH experts always notice when the coffee machines are switched on at about 8 a.m. in Hamburg, because this causes small fluctuations in the grid, which the physicists then have to compensate for in the FLASH control room.

FLASH has been operating on a routine basis ever since 2005, and is available to researchers from all over the world. The short wavelengths of the flashes are interesting to researchers for one reason in particular: they can be used to investigate a sample in extremely fine details. Besides, the pulses are so strong that it is often possible to make a definitive measurement using only a single flash. That is an important prerequisite for analysing biological samples, for instance.
But many other disciplines also benefit from FLASH. Physicists use the superlaser to investigate individual nanoparticles and thus to deduce important basic principles for nanotechnology. With the help of the X-ray flashes, astrophysicists can analyse matter that can normally only be found in space – such as the highly charged iron ions that occur in the sun’s atmosphere. By means of “pump and probe” experiments, other researchers observe the course of chemical reactions or the melting of surfaces. Another “conventional” laser has been set up in the measuring hall for this purpose. It generates short pulses of visible light and thus fires the starting shot for each of these reactions. While the reaction takes place, FLASH observes the microscopic spectacle with its short pulses of soft X-ray radiation.

The research community is tremendously interested in these processes. Today, more than 300 experts from 18 countries have studied their samples in the high-intensity light generated by FLASH. However, not every scientist who would like to work with the intense X-ray flashes is able to do so, because FLASH is completely overbooked – a source of pride for its developers. Besides, the facility is the prototype for an even bigger laser that will be more than three kilometres long and is currently being built in Hamburg. It is known as the European XFEL X-ray free-electron laser.
The key components of FLASH are superconducting accelerator structures, which are known in the researchers’ professional jargon as cavity resonators. This pioneering accelerator technology of the future has been developed and constantly refined at DESY since the early 1990s in close cooperation with industrial companies and many partner institutes in Germany and abroad.

Conventional cavities are made of copper. They function on the principle that strong transmitters generate intense electromagnetic waves with a frequency in the radio-wave range. These strong waves are fed into the cavities, specially shaped metre-long copper pipes that are set into the accelerators. The pipes are shaped in such a way that the radio waves fit inside them just about perfectly. When the particles to be accelerated – for example, electrons – fly into the cavity, they are in effect grabbed by a crest of the radio wave. The electrons then “ride” this crest in the same way that surfers ride an Atlantic wave, and they receive a substantial energy boost in the process. But the problem with these conventional copper cavities is that they display electrical resistance, similar to an electric wire made of copper, and that causes a significant loss of energy – which in turn leads to exorbitant electricity bills.

With the TESLA technology, that does not happen. Here, the cavities consist of niobium metal. If this niobium is cooled down to approximately minus 271 degrees Celsius, it becomes superconducting. In other words, it loses its electric resistance and conducts electric current without any losses whatsoever. As a result, almost all of the energy fed into the cavities can be transferred to the electrons. This technology offers several advantages. For one thing, it is possible to save energy. For another, the superconducting cavities help to bundle the electrons into fine, highly precise bunches and to accelerate many of these bunches in rapid succession. And that is a tremendous advantage for not just a particle physics machine but also for XUV and X-ray lasers. For the collider, the technology makes it possible to achieve especially high collision rates for the accelerated electrons and positrons; for the lasers, it enables very precisely focused flashes of radiation.

However, the technology involved is extremely challenging. For example, the superconducting niobium cavities must be cooled with liquid helium throughout their entire length to minus 271 degrees Celsius – a temperature similar to that of outer space. To prevent the cavities from warming up, they are packed in so-called cryostats – metre-wide, extremely well-insulated metal pipes that serve as oversized thermosts flasks. Manufacturing the superconducting cavities is also a delicate process. Even a couple of dust grains on their surface would be enough to cause the superconductivity to break down and make the pipes unusable. That is why the accelerator modules have to be manufactured and assembled in a cleanroom. Here the air is filtered so thoroughly that it contains only one hundred-thousandth of the dust that whirls around in normal city air.
Everything under control
Katja Honkavaara casts a relaxed glance at one of the many flat screens in the DESY control room. All of the indicators are green, which means the machine is running smoothly. “We’re having a quiet day today,” says Honkavaara, who was born in Finland, with visible satisfaction. She is one of the people who are responsible for making sure that FLASH runs as smoothly as possible, and reliably provides the scientists in the experimental hall with X-ray flashes 24 hours a day, seven days a week. “To make sure that happens, we operate three shifts here around the clock,” she explains.

This means that Honkavaara and her colleagues are sitting at the consoles day and night to make sure that the 260-metre-long accelerator is accelerating extremely fine electron bunches and that they are positioned between the undulator magnets in such a way that highly intense laser flashes are generated. The work they do in the control room is far from routine. After all, FLASH is not a conventional machine but a prototype that is one of a kind. “We can’t simply turn on the machine and expect it to work automatically,” says Honkavaara. “We have to monitor it constantly.”

That is because FLASH does not operate this smoothly every day. It is not rare to see one of the indicators on the monitors jump from green to red. When that happens, the operator has to react quickly and make adjustments to one of the numerous parameters. And sometimes one of the components breaks down, so that specialists have to step in to correct the defect as soon as possible.

As the FLASH coordinator, Honkavaara is also frequently scheduled for standby duty. “If a problem occurs that the operators can’t solve, they can call me at any time, day or night,” she says. If necessary, she can log into the FLASH control system from her home computer and look for the error via a remote-diagnosis system. But if that’s not sufficient, she has to get into her car and rush over to DESY – sometimes in the middle of the night.

Things also get tense when Honkavaara and her colleagues conduct “machine studies”. In this process, they systematically tinker with the machine or test new components with the aim of generating even more light from the free-electron laser. “After all, one purpose of FLASH is to try out the TESLA technology and refine it even further,” she says. “Our experiences will also be used later on for the operation of the European XFEL X-ray laser and the development of the International Linear Collider.”

Honkavaara, who has been working at DESY since 2000, has watched the FLASH project grow step by step. “It was an exciting experience every time the machine was restarted after an upgrade was made and we waited to see whether it was functioning as planned,” she says. So far, FLASH has always fulfilled its creators’ expectations. They hope this will also be the case for the next phase of expansion, when additional accelerator modules will be inserted into the machine in order to generate X-ray wavelengths of less than five nanometres. When that happens, the control room managed by Honkavaara and her team will not be as quiet as it is now – it will be full of action and excitement.
09: PETRA III

PETRA III is one of the brightest storage rings worldwide

SUPER SOURCE FOR X-RAY LIGHT
Super source for X-ray light

PETRA III is one of the brightest storage rings worldwide

The hall is gigantic. It is nearly 300 metres long, relatively narrow – and looks a bit like a banana when viewed from above. Its most remarkable feature is underfoot, however: the concrete floor is the longest monolithic concrete slab in the world. The amazing structure is part of the most recent major project at DESY, which has just been completed: PETRA III, one of the “brightest” storage rings worldwide.

The PETRA accelerator has a fascinating past. Construction began in 1975. Three years later the first electrons began circling the 2.3-kilometre-long facility, which at the time was the world’s largest storage ring. When the very successful programme of the very successful experimental programme concluded in 1986, the DESY experts reconfigured the machine as PETRA II, a pre-accelerator for the gigantic HERA ring. A new purpose for PETRA was quickly found when the HERA programme concluded in 2007: with its dimensions, PETRA was predestined to become an ultra-high-performance X-ray source.
DESY researchers had, in fact, installed several experimental stations in PETRA II with which they were able to generate high-intensity X-rays more or less as a by-product of the primary operation of the accelerator. A complex, 225-million-euro reconfiguration was necessary to create a powerful, cutting-edge light source, however. Not only did the DESY experts have to replace magnets, vacuum systems, measurement and control technology and power and cooling water supply systems; one eighth of the ring had to be completely redesigned so that 14 undulators could be installed over time. When the fast particles fly through these special magnets, they emit particularly strong and focused synchrotron radiation.

To make room for the experiments, the nearly 300-metre-long experimental hall with the oversized concrete slab was erected. It contains 14 evacuated pipes that guide the X-ray light to up to 30 special “huts” in which the actual experiments are conducted.
A special feature of PETRA III is that it is the world's most brilliant storage ring for certain wavelengths, i.e. “X-ray colours”. At these wavelengths, it shines more intensely than any comparable ring anywhere in the world – for example, it is brighter than the European Synchrotron Radiation Facility ESRF in Grenoble, France. The PETRA light is also in part much more strongly focused than that of the competition: the X-ray beams in Hamburg are up to one thousand times finer than a human hair. In some cases the radiation can be concentrated on an area measuring only a few nanometres, which is important when the aim is to study minuscule samples or sections of samples.

The researchers had to build and calibrate the facility with the utmost precision to be able to direct PETRA’s nanobeams at a sample with true accuracy. To prevent the images from blurring, it is very important that the experimental setups be kept as vibration-free as possible. This is the purpose of the thick, monolithic concrete slab. It dampens vibrations from footsteps, for example, so effectively that hardly any vibrations make it through to the experiments.

What do the researchers intend to do with PETRA III? Biologists would like to study protein molecules in much greater detail than was previously possible. This requires growing the proteins into crystals – often an extremely laborious undertaking. The stronger the X-ray beam directed at the sample, the smaller the biocrystal can be. The experts at the European Molecular Biology Laboratory EMBL, for example, will have their own special-built research facility where they will use the bright light from PETRA III to study in detail those proteins that do not readily crystallize. On the agenda are giant biological molecules such as the “protein factory” ribosome and proteins in muscle that enable movement. With their experiments, the researchers are also striving to lay the foundation for novel medicines.
Before Gerhard Materlik left HASYLAB in 2001, he had spent many years as head of the laboratory and also initiated the FEL activities at DESY. He then built a new, state-of-the-art X-ray source in England – and is now looking with interest to Hamburg, where PETRA III was recently completed.

Tell us about the facility that you built in England and now head.

Gerhard Materlik: The storage ring is called Diamond Light Source and is the UK national synchrotron radiation source. The ring is operated with an electron energy of 3 GeV, is 562 meters in circumference and is optimized for the production of X-rays with wavelengths in the tenths of a nanometre range. This range is enormously important for numerous structural investigations, such as to decipher the precise atomic structure of a protein or a virus. Diamond also has a very low beam emittance, i.e. a very high brilliance that can be concentrated on a very small spot. The facility became operational in January 2007, and we have been expanding it ever since.

How is Diamond different from PETRA III?
With a circumference of 2.3 kilometres, PETRA III is a good bit larger than our storage ring. And with its electron energy of 6 GeV, PETRA III is capable of generating X-rays with much shorter wavelengths. Furthermore, the physicists at DESY are aiming to achieve even lower beam emittance, with the target being roughly half the value attained at our facility. That is certainly a challenge. To achieve such a low emittance in an experiment, great care must be taken for example to ensure that the floor on which the facility is installed is extremely stable and vibration-free. The slightest vibration in the floor affects the stability of the X-ray beams. I am certain, however, that my colleagues in Hamburg took all of this into consideration when designing PETRA III and will ultimately achieve their goal.

Will PETRA III be able to perform experiments that could not be performed like this, if at all, elsewhere?
The strengths of PETRA III lie in experiments for which very short-wavelength X-ray radiation is required. The object of such experiments is to investigate mechanical stresses in the interior of materials, for example. Because short-wavelength X-rays are also not as strongly absorbed by matter, they can be used to effectively study relatively thick specimens. As you can see, PETRA III is unmatched anywhere in the world when it comes to the generation of very short wavelengths. If you want to study biomolecules, on the other hand, a facility like Diamond is certainly at least its peer.
An experiment in the PETRA III hall
Other researchers are focusing on inanimate objects – rocks. The X-ray “magnifying glass” can be used to study microscopic diamonds embedded in some rocks. The diamonds, which were formed deep below the surface of the earth, are of interest because they act as a sort of archive and disclose fascinating details about the extreme conditions prevailing in the earth’s mantle.

Experts at the GKSS research centre in Geesthacht, Germany, would like to check the quality of welding seams, study signs of fatigue in workpieces and inspect novel metal alloys such as those being developed for the cars of the future. They benefit from the fact that PETRA III produces not only very brilliant, but also very “hard”, i.e. short-wavelength X-rays. These penetrate significantly deeper into metallic materials than “softer” X-ray light, which has the disadvantage of literally bouncing off of the surface of steel or iron. With the PETRA light, researchers can thus look more deeply into materials than ever before to detect minuscule, undesired bubbles or pores that reduce the service life of lightweight components.

The big moment came on 16 April 2009: at exactly 10:14 a.m., the first bunches of particles began racing around PETRA III. The ring delivered its first light three months later, on 17 July. The Hamburg super lamp will be available for routine operation from 2010 – and not just to research teams from Germany, but from around the world.
10: European XFEL

The world’s most powerful X-ray laser is currently under construction in Hamburg.

GREEN LIGHT FOR FREE ELECTRONS
Green light for free electrons

The world’s most powerful X-ray laser is currently under construction in Hamburg.

“We are witnessing the creation of something truly world class!” announced Annette Schavan, Germany’s Minister of Education and Research, at a ceremony that took place on 5 June 2007 to launch the construction of what will be one of the largest scientific facilities in Europe. From 2014 onwards, an X-ray free-electron laser in the Hamburg metropolitan area will provide the world’s most powerful X-ray light. Known as the European XFEL, it will enable a whole new class of experiments.

At the heart of the European XFEL is an electron accelerator some two kilometres in length. To be installed in a concrete tunnel underground, it will run in a north-westerly direction from the DESY site in the Bahrenfeld district of Hamburg to an industrial estate in the town of Schenefeld, just beyond the state boundary with Schleswig-Holstein. It is here that the European XFEL research campus is now being built. As with the smaller free-electron laser FLASH, the new accelerator will use superconducting technology developed for the TESLA project.
The idea for the European XFEL arose in the 1990s. It was initially conceived as part of the TESLA project – a planned 30-kilometre-long facility. TESLA was to combine the world’s largest electron-positron accelerator for particle physics with the most powerful X-ray laser ever. For a number of reasons, not least cost, the project was split into two in 2003. The accelerator has since been incorporated in the international ILC project, a huge linear collider facility that is currently being planned by teams around the globe. The X-ray laser, meanwhile, is now under construction as a European project in Hamburg.

But how does the European XFEL actually work? First of all, electrons travelling at almost the speed of light are brought to high energies by a superconducting accelerator just under two kilometres in length. These electrons then race through undulators – arrangements of special magnets – thereby emitting energy in the form of extremely powerful flashes of X-ray light. These flashes are up to a billion times more intense than the light from storage rings, currently the most powerful X-ray sources. At the same time, it is also possible to vary the wavelength of the flashes within a range of six and 0.1 nanometres. This makes it possible to observe samples in minuscule, atomic detail.

Furthermore, the flashes are less than a trillionth of a second in length, which makes them ideal for analysing extremely fast processes such as chemical reactions. Finally, the flashes have laser properties. In principle, they are therefore suitable for producing holograms, i.e. three-dimensional images.

Basic research in a whole range of disciplines is set to benefit from this new laser. Molecular biologists, for example, are hoping to capture detailed images of individual protein molecules. This should help with the customized design of new medicines. Astrophysicists, meanwhile, should be able to discover more about the nature of matter inside stars. Geologists are planning to use the European XFEL to see what happens when rock samples are subjected to artificial shock waves. Their aim is to simulate the enormous pressures at the earth’s core and thereby discover more about what goes on within our planet. And, last but not least, chemists hope to be able to capture chemical reactions on film and thereby observe in slow motion how individual atoms react with one another. This knowledge could then be used to develop more efficient production processes for industry.
Electrons that undulate

A free-electron laser can produce X-rays because of a neat principle known as self-amplified spontaneous emission, or SASE for short. Tiny bunches of electrons are brought to high energies in a linear accelerator. Each bunch contains around 10 billion electrons. At the end of the accelerator, these bunches fly through an approximately 200-metre-long arrangement of special magnets known as an undulator. This makes the electron bunches follow a zigzag path, which in turn causes each individual electron to emit X-ray light.

As this light is travelling slightly faster than the electrons, it overtakes those just ahead. In so doing, it accelerates some of the electrons and decelerates others. As a result, the electrons are gradually grouped into a large number of thin “slices”. By the end of the undulator, this process of slice formation is complete.

Most importantly of all, all the electrons in any given slice are now emitting X-rays in phase – a process that is self-amplifying. This results in extremely intense flashes of laser light – the world’s most powerful X-rays.

In order for the SASE principle to take effect, it is essential that the electron beam be of an exceptionally high quality. In other words, it must be composed of electron bunches a mere 50 micrometers across, each made up of 10 billion particles possessing, ideally, the same energy and direction of flight. A superconducting linear accelerator like the one planned for the European XFEL is highly effective at generating such a beam. FLASH also makes use of the SASE principle, although it does so for light of longer wavelengths (UV radiation and soft X-rays).
As the name indicates, the European XFEL is not a German but rather a major international project, which involves, alongside Germany, a total of 13 countries, including France, the UK, Switzerland, Russia and China. Although the X-ray laser project was largely initiated and developed by DESY, the facility is being built, and will be operated, by a specially created company called European XFEL GmbH. The costs of the project amount to around 1 billion euros, a good half of which is being funded by Germany, with the lion’s share coming from the federal government plus substantial contributions from the states of Hamburg and Schleswig-Holstein. The rest is being provided by the partner countries. DESY is coordinating the construction of the accelerator.

However, rival projects are also under way. Both Japan and the USA are in the process of building and, indeed, commissioning X-ray lasers of a similar scale. Yet neither employs a superconducting accelerator, which is why they only generate 120 X-ray flashes per second. By way of comparison, the European XFEL will be capable of 30,000 flashes per second, a performance with decisive benefits for many experiments. Furthermore, it will be able to supply a number of measuring stations with X-rays simultaneously.

In their quest to trace the course of chemical reactions in ever greater detail, researchers today work with inconceivably small fragments of time. A quadrillionth of a second – known as a femtosecond – is all it takes for two molecules to form or break a chemical bond. With the help of an ultrafast laser, which enables exposure times in the femtosecond range, it is possible to capture snapshot images of this process. An initial laser pulse triggers the photochemical reaction; this is followed by a second flash, much like a speed camera when recording a vehicle that is travelling too fast. The second flash is sent at varying intervals, thus providing the exposure for a series of snapshots that, in combination, will yield a veritable slide show of the reaction in all its different stages.

With the European XFEL, it will be possible to produce slide shows of the microcosm in unrivalled detail. Indeed, a single laser flash will be so bright that it will generate images of reacting molecules at a resolution right down to individual atoms. In other words, the European XFEL will enable researchers to follow and understand the course of chemical reactions in extremely precise detail. This will be useful in a whole range of fields, including optoelectronics, fuel cell technology, the solar cell industry and the development of new catalytic converters for the automotive sector.
A physicist with managerial qualities

Massimo Altarelli heads the project team for the European XFEL

Massimo Altarelli glances out of his office window at the gloomy Hamburg sky. Coming from Italy, he is certainly used to better weather. Nonetheless, his spirits are high. “I’ve got a very exciting job here!” explains the physicist. Altarelli is in charge of the European XFEL, currently one of the largest scientific projects in Europe.

The post requires proven management skills. After all, it is Altarelli’s job to see that a completely new type of high-tech facility gets built on schedule and to budget. Furthermore, there is the small matter of accommodating the interests of researchers and government agencies from a total of 14 countries.

Fortunately, Altarelli has experience in organizing major international projects. In the 1980s and 1990s, he was Director of Research at the European Synchrotron Radiation Facility ESRF in Grenoble, France, where he helped oversee the construction of one the world’s most brilliant storage rings, a project involving 18 European countries. “We built the facility on a greenfield site,” Altarelli recalls. “Today, the ESRF is a laboratory of world repute.”

As plans emerged to build the European XFEL – a totally new and spectacular scientific facility – Altarelli was immediately interested. “In terms of light sources, the European XFEL is the largest and most exciting of current projects in Europe and possibly even the world,” he explains. Part of the attraction of the job at the ESRF, he adds, was helping to coordinate the international cooperation. “Here in Hamburg, I saw a chance to repeat that experience.”

The European XFEL, he explains, brings together two great achievements in the world of physics: on the one hand, the use of X-rays to investigate in detail the atomic structure of a particular material – which is of crucial importance for a fundamental understanding of its properties; on the other, the use of ultrashort pulses of light with laser properties to observe ultrafast processes. “The European XFEL combines both of these research tools,” says Altarelli. “It will enable us to analyse the atomic structure of matter and, at the same time, to observe how the atoms move and what they do.”

Altarelli underlines that there’s still really no way of knowing just what the European XFEL will be usable for in the future. “It will certainly enable experiments that we’re not even thinking about today.” But do such prospects compensate for the Hamburg weather? Altarelli looks out of the window and laughs. “You can’t have everything.” The sun may shine more often in Italy. “But the job here more than makes up for that!”
AN EXCURSION TO GENEVA
An excursion to Geneva

DESY physicists experiment at the LHC, the world’s biggest accelerator

The elevator takes almost one minute to go down only one floor. Then, 100 metres underground, the door opens. After just a few steps down a corridor, the visitor is standing in a hall as big as a cathedral – facing an object as big as an office building, packed full of thousands of highly sensitive sensors. It is CMS, one of the detectors at the LHC in Geneva, Switzerland, the biggest accelerator in the world. The gigantic detector was designed and built by roughly 2000 physicists from all over the world – including about three dozen experts from DESY.

The Large Hadron Collider is the most powerful accelerator of all time. It is built into a 27-kilometer-long ring tunnel at the European particle research centre CERN. Until 2000 this tunnel contained a different particle accelerator, called LEP. But while the LEP fired electrons and positrons at each other, the LHC accelerates protons (hydrogen nuclei). Protons are nearly 2000 times heavier than electrons, so the impact of the head-on collisions is much greater – as is therefore the chance of producing unknown elementary particles.

SUSY, Higgs and the primordial cosmic soup

What the LHC might discover

The origin of mass
Why do the elementary building blocks of matter, for example quarks, have mass in the first place? The prevalent theory of particle physics, the Standard Model, responds by predicting the existence of a new particle, called the Higgs boson. The idea was originally postulated by the British physicist Peter Higgs, who proposed that the universe is permeated by a field that is a little bit like treacle, offering resistance to all other particles. It is this resistance that is perceived as mass. If the LHC finds the Higgs boson, the thesis would be proven.

Dark matter
Only about five percent of the universe consists of matter. The rest is made up of “dark”, or invisible, matter and a mysterious dark energy. Behind the dark matter, many theorists believe, might be a thing called SUSY particles; SUSY stands for supersymmetry. Should the LHC track down such SUSY particles, it would mean more than shedding light on the mystery of dark matter. At the same time it would simplify researchers’ perception of the physical universe: supersymmetry would in fact bring together two previously separate pillars of physics – the particles and the forces – in a single theory.
The LHC’s tunnel is a concrete tube similar to an underground rail tunnel. It contains two stainless steel beam pipes under ultrahigh vacuum. Many billions of protons circle through these pipes, which are just a few centimetres in diameter. The protons, packed into bunches, fly through these pipes – one pipe for each direction. The protons are held on course on their way through the ring by superstrong magnets. The magnets are superconducting and have to be cooled by liquid helium to about minus 270 degrees Celsius. For that job, CERN built the world’s most powerful “refrigerator”.

At four points in the 27-kilometre ring, the physicists cause the protons to collide head-on with one another. Thanks to the brilliant work of Albert Einstein we now know that these collisions can be used to create new particles: mass (m) can be converted into energy (E) and vice versa – the finding expressed in Einstein’s famous formula $E=mc^2$. The LHC pumps more kinetic energy into the protons than has previously been possible with any other accelerator. When the protons collide, a large part of their kinetic energy is converted into mass: new, heavy particles that were previously unknown are born.

**Primordial cosmic soup**
Within fractions of a second after the big bang, the universe consisted of an extremely hot “soup” in which quarks and their “glue” particles – the gluons discovered at DESY – were also swimming. The LHC is to reheat this quark-gluon plasma and investigate it in detail. To do this, the LHC will shoot lead nuclei at each other instead of creating proton collisions. The events are to be analysed by a detector named ALICE. The challenge lies in the fact that lead collisions produce tens of thousands of new particles – many more than the proton experiments. ALICE will try to detect as many of these particles as possible.

**Mysterious antimatter**
There is lots of matter in the universe, but hardly any antimatter – a fact that has been puzzling physicists for decades. The LHC is to get to the bottom of the mystery by finding new, striking differences in the behaviour of matter and antimatter. The LHCb detector will be hunting for special exotic particles the LHC will churn out: the B mesons. Their decay should help to explain why all antimatter disappeared from our universe while some matter remained.
To observe these processes in the greatest detail possible, enormous detectors are positioned at the four collision points. In all, more than 9000 experts are taking part in these mega-experiments. DESY researchers are also working on another “particle camera” besides CMS. Called ATLAS, it is 25 metres high and wide, and 46 metres long, making it the biggest detector at the LHC.

ATLAS and CMS can rightfully be considered to be the most technologically challenging scientific instruments ever built. Their detector technology is based in part on new methods that have hardly been put to the test. In the centre of the CMS detector, for example, there are more than 200 square metres of ultrapure silicon sensors, connected by a labyrinth of thousands of special cables. Their job is to measure with maximum precision the tracks of the particles created during the collision.

Each detector produces huge amounts of data – in one day the equivalent of the content of roughly 30,000 CDs. In order to process this data, the experts developed an entirely new computing concept, the GRID. This involves the intelligent interconnection of dozens of computer centres all over the world, enabling them to provide their combined computing power.
What exactly are you and your DESY colleagues working on in Geneva?

Klaus Mönig: We are mainly involved in something called the trigger and in software development for ATLAS. But we are also taking part in building the luminosity detector, one of the many subsystems of ATLAS. It stands at a distance of 240 metres from the detector itself and measures the “hit rate” at which the protons collide. We also are conducting development work for an ATLAS upgrade, which is expected to begin in about 2015 and will be necessary for the planned expansion of the LHC into the “Super LHC”. With this Super LHC we hope to once again significantly increase the hit rate of the protons. That will require entirely new components for the ATLAS detector, and we are helping to develop them.

How many DESY researchers are working on ATLAS?

There currently are 24 physicists and 14 PhD students devoting most of their working hours to the ATLAS project. We can contribute, among other things, the experience we have gained with the DESY accelerator HERA and its detectors. What’s more, DESY is operating one of the computing centres for the GRID, which will help conduct the subsequent analysis of the measured data.

Do you spend most of your time in Geneva or can you also work from Germany?

These days, it is possible to do a lot from DESY. Regardless of where we work from, though, we spend about 90 percent of the time behind the computer. And with the quality of today’s computer networks, it’s no problem to carry out the work from an external location. Nevertheless there are always four or five DESY researchers in Geneva because for some jobs you simply have to be on site. The others then regularly come to CERN for work meetings.

The ATLAS team has been working on the detector since the mid-1990s. The DESY researchers didn’t join in until 2005, which was fairly late in the game. Was your involvement well-received from the start, or did you first have to prove yourselves as part of this team of more than 2000 researchers?

Both. An experiment like ATLAS is highly complex, so additional expertise is always needed. There was a need for more manpower, especially for the work on the trigger and the software, so DESY was welcomed with open arms. Even so, we had to begin by working our way up. By now things are going smoothly, though, and today we are a fully integrated member of the ATLAS team, with group members in supervisory positions.
HOT PLANS AND A COOL DECISION

12: ILC

The future ILC accelerator will use innovative DESY technology.
Hot plans
and a cool decision

The future ILC accelerator will use innovative DESY technology

20 August, 2004, Beijing, China.
A decision announced at a physics conference brings delight and satisfaction to the researchers in Hamburg: the International Linear Collider ILC, a gigantic particle accelerator planned for international use in the future, is to be based on the superconducting TESLA technology that was largely developed at DESY.

Straight rather than circular
How the ILC differs from other accelerators

As a rule, major particle accelerators – such as the PETRA and HERA rings in Hamburg – used to be circular. But now, physicists are exploring a different direction with the ILC, which will be straight as an arrow. At first glance, this would seem to be a disadvantage. When particles are accelerated in a straight line rather than in a ring, they cannot race through the accelerating beam pipes tens of thousands of times while receiving repeated “pushes” – they can only travel through the beam pipe once. However – and this is the crucial advantage – in the ILC there is no loss whatsoever caused by the synchrotron radiation that electrons give off as they fly round the ring of a circular accelerator.

As a result, thanks to its extremely powerful superconducting accelerator beam pipes, the ILC will shoot electrons and positrons at each other with an energy of initially 500 gigaelectronvolts – two and a half times the former record achieved by the 27-kilometre-long LEP ring in Geneva. The ILC is also gigantic, consisting of two 15-kilometre-long tunnels positioned opposite each other. One houses the electron accelerator; the other, the positron accelerator. The extremely collimated particle bunches collide at full speed in the middle – 14,000 times a second. This is where the gigantic ILC detectors are positioned. They observe the process in order to see which new, possibly yet unknown, building blocks of matter have been generated in the collisions.
In 2001 the international community of particle physics researchers decided to implement the concept of the International Linear Collider as a logical supplement to the LHC in Geneva. However, the best way to construct this gigantic facility, which would be approximately 30 kilometres long, was still a matter of controversy. The Americans and the Japanese in particular favoured the so-called “warm technology”. Here, the particles are accelerated by strong electromagnetic waves as they fly through metal beam pipes made of copper. The beam pipes function at room temperature, but they offer significant electrical resistance, which leads to energy losses and thus to higher electricity bills.

This is not the case with superconducting accelerator beam pipes made of the metal niobium – a technology that was developed by DESY in cooperation with industrial companies and various scientific institutes in Germany and abroad as part of the TESLA project. It is true that the niobium has to be cooled off to about minus 270 degrees Celsius with the aid of liquid helium – hence the name “cold technology”. But at these extremely cold temperatures, superconductivity sets in. This means that the currents can flow through the beam pipes with virtually no resistance. There is hardly any loss of energy, and the acceleration process is thus extremely efficient.

The researchers are also considering to extend the machine to a length of 50 kilometres in a subsequent phase of expansion. This would make it possible to double the collision energy, from 500 gigaelectronvolts to one teraelectronvolt.

Scientists expect the ILC to help them solve some of the most perplexing riddles in particle physics research. How do the building blocks of matter acquire their mass? How are matter and the different forces related to one another? And what is dark matter all about? As physicists try to answer these questions, the ILC will be the ideal complement to another major particle accelerator, the LHC in Geneva. Indeed, the LHC fires protons, rather than electrons and positrons, at one another. This generates considerably more energy than the collision of an electron and a positron – but the collision events in the ILC can be evaluated much more precisely than the processes taking place in Geneva. The result would be a shared labour: the LHC is a discovery machine for detecting the possible existence of SUSY particles and Higgs bosons. By contrast, the ILC will be a precision machine that will enable researchers to examine the exotic particles very closely – an absolute prerequisite if they are to be able to test the validity of new theories of physics.
The superconducting accelerator is the heart of the ILC.
But which concept – warm or cold – is ultimately better? To answer this question, the International Committee for Future Accelerators appointed a panel of experts in summer 2003. The outcome of the contest was regarded as completely open until the panel announced its decision in Beijing in August 2004: the ILC was to run with cold, rather than warm, technology. According to the jury, a cold accelerator would consume less energy than a warm one, operate more reliably and be based on an important prototype, the European XFEL.

The advocates of warm technology were only disappointed for a short time, as they quickly reconciled themselves to the cold technology and joined in the work. Today, the ILC is a global project, even though it is still not clear where it is going to be built. More than 2000 researchers from over 300 institutes and well over two dozen countries are participating in the multi-billion-euro project. The preparations are in full swing at almost all of the major particle accelerator centres in the world. At test facilities in Chicago, USA, Hamburg, Germany, and Tsukuba, Japan, physicists are working to perfect the required technology and optimize the construction plans for the new super-accelerator down to the last detail.

At the end of 2012, when the first results of the LHC are expected to be available, the ILC community plans to publish a Technical Design Report that will contain the information to be presented to the funding agencies and candidates for its future location. Until then, the researchers at DESY will refine the acceleration technology and optimize the assembly processes with the help of first-hand experience provided by the construction of the European XFEL. In addition, they are involved in the central management of the ILC and the development of detectors for the new super-accelerator, both of which present bigger challenges with regard to precision and reliability than ever before.
“We need the ILC!”

From 1999 to 2009, Albrecht Wagner was the Director of DESY - and helped to launch the ILC project.

No decision has so far been made as to where the ILC will be built. What will happen if it’s built somewhere other than Hamburg?

Cutting-edge research can certainly be done even if you don’t have your own accelerator. For example, astronomers who work with satellite telescopes don’t have their research instruments outside the front door; they have them in space. The fields of astronomy and space exploration have proved that this kind of distributed scientific research can work well. However, it’s important to make sure that at your location you’ve got a critical mass of clever people who are driving progress in your field of research. We want to maintain this culture at DESY in the future.

What’s more, today accelerators and detectors can be operated from a distance, thanks to fast data connections. We’re already performing this feat with the LHC detectors in Geneva and with the ILC test experiments that are being conducted at Fermilab in Chicago, at DESY and at CERN. So you don’t have to be on the spot in order to use a certain machine for your experiments. And the ILC will eventually have this kind of global accelerator network as well. This will enable us to maintain our strong position at DESY even if the accelerator is located somewhere else.

Is the ILC project proceeding as planned?

It’s making steady and significant progress. The partners are currently working on the detailed construction plans and refining the design of the facility down to the tiniest detail — in terms of optimizing costs, among other things. The focus is on the further development of the superconducting accelerator beam pipes. The decision about when and where the ILC will be built will probably not be made until the LHC in Geneva has delivered initial results. But the international community of particle physicists is saying very clearly that “no matter what kind of observations we’re going to make with the LHC, we need the ILC!”

What role is DESY playing in the development of the future ILC accelerator?

Albrecht Wagner: Superconducting TESLA technology is at the heart of the ILC. Ever since the early 1990s, DESY has served as a crystallization point, where the world’s combined knowledge of superconducting accelerators has flowed together. This concentrated knowledge has made it possible to achieve fast and impressive progress. And that’s exactly what led in 2004 to the decision to use the TESLA technology for the ILC. Ever since then, there’s been no way to make any moves in this field without taking DESY into account — especially since there are two facilities in Hamburg, FLASH and the European XFEL X-ray laser, that are also based on superconducting technology. As a result, we are able to gather valuable experience not only in terms of the construction and operation of the acceleration beam pipes but also regarding cooperation with partners from industry. DESY is thus always a step ahead of the other laboratories in the world.
THE POWERS BEHIND THE SCENES
The powers behind the scenes

Hundreds of experts keep the DESY infrastructure running

DESY was founded in December 1959 in order to conduct cutting-edge research – initially in particle physics, and later also as a centre of X-ray radiation sources. But scientists can do their work successfully only if they have a supportive framework and the infrastructure works smoothly. And this infrastructure includes many components, from administrative offices, workshops and computer centres to libraries and canteens.

The accelerators at DESY have always pushed the limits of what was technologically feasible. Many of the components that are needed to build the devices involved are not available “off the shelf”, but have to be specially designed and constructed.

The experts at DESY construct many of these special devices on their own. They receive valuable support from the centre’s own workshops. For example, the electronics service centre helps to develop highly specialized electronic measuring and control units that are needed by researchers in particle physics as well as scientists working with X-ray sources.
DESY also conducts outreach programmes aimed at the general public. For example, approximately 8000 interested members of the public participate in visitor tours every year. There are also regular “open door” events and lectures that are pitched at a level that is understandable for non-scientists. The public is invited to participate in informal discussions about scientific topics at the “Science Café”, and the “physik. begreifen” laboratory for schoolchildren has been very successful in getting children and teenagers enthusiastic about physics.

The mechanics service centre specializes in the creation of precision-engineering components; at the workbenches, the focus is almost always on achieving the very highest degrees of precision. Not only the workshops but also the administrative departments offer young people the opportunity to complete interesting training courses that equip them with high qualifications in a variety of commercial and technical fields.

For most of the researchers at DESY, it is not enough to work only at the computers on their desks. For their analyses and simulations, they need the concentrated calculating power of supercomputers and parallel computers. The IT group at DESY is responsible for ensuring that these machines always work quickly and reliably. Especially useful in this regard is the innovative GRID technology, a new computer architecture that is needed for the extensive data analyses of the LHC detector readings.
Fun instead of rote learning
“physik.begreifen”, the school laboratory at DESY

In 1996 the Administrative Director of DESY at the time, Helmut Krech, had a brilliant idea: creating a laboratory at DESY where schoolchildren could perform experiments in a playful atmosphere and thus overcome their prejudices against the supposedly boring subject of physics. Today this school laboratory, known as “physik.begreifen”, is in great demand. In addition to the lab in Hamburg, a second one was set up in 2004 in Zeuthen.

“We’ve got the oldest school laboratory in the Helmholtz Association,” says Uta Langenbuch, who is responsible for continuing education at DESY. “We started out in 1996 with an empty office and a whole lot of ideas. We thought it was important to offer experiments that don’t require the children to have any previous knowledge from their classes in school.” That is why they created the vacuum laboratory as their first offering. Here, children who are finishing their primary education can put balloons or chocolate-coated marshmallow treats under a bell jar, create a vacuum and make them explode. Since 2004, the school lab has also been offering continuing education courses for pre-school and primary school teachers. Here the teachers can also try out experiments that they can use in their own classrooms.

In 2001 the school lab project expanded its range of offerings by adding a radioactivity laboratory. Here, teenagers in the 15 to 16-year-old age group can investigate whether certain salts are radioactive and how to effectively shield off the different types of radiation. And since 2005, the quantum laboratory has been in place for students in the final stages of secondary school. Here the students can investigate quantum phenomena that contradict our everyday experience. The physik.begreifen team led by Uta Langenbuch is currently creating two new laboratories dealing with the themes “Particles and Fields” and “Magnetism.”

“Through our experiments we are reaching even schoolchildren who normally say, ‘I can’t do physics, and I don’t like it either,’” says Langenbuch. As a result, when the children leave the DESY laboratories, most of them are extremely enthusiastic about physics. “We often hear children say, ‘I’ve learned more about physics today than in all my years at school!’” Langenbuch reports.

Today, more than 7500 schoolchildren attend sessions at the laboratories in Hamburg and Zeuthen every year. “We get so many requests that it’s impossible to accommodate all of them,” she says. “After we announce the lab dates for the following six months, people have to call within the next two hours to make an appointment. If they don’t, they won’t get a place!”
Facts & figures

Deutsches Elektronen-Synchrotron
A Research Centre of
the Helmholtz Association

A publicly funded
national research centre

Established in Hamburg on
18 December 1959

Locations:
Hamburg and Zeuthen (Brandenburg)

Budget:
192 million euros (Hamburg:
173 million, Zeuthen: 19 million)

Funding:
90% on the national level (Federal
Ministry of Education and Research);
10% on the state level (the city
of Hamburg and the state of
Brandenburg)

Employees:
Approximately 2000, including some
650 scientists working in the areas of
accelerator operation, research and
development

Guest researchers:
More than 2000 from
more than 40 countries annually

Training programmes:
More than 100 young people are
being trained in commercial and
technical vocations

Young scientists:
Around 700 graduate students,
PhD students and postdocs