Chapter 6
To DESY via CERN

In 1970, the Schoppers moved to Geneva. Herwig had been offered a position as head of the laboratory's Nuclear Physics Division, and he took unpaid leave of absence from Karlsruhe to take up the post. It was a timely move, since following his first stint at CERN, he'd set up a CERN user group at Karlsruhe, doing experiments at the proton synchrotron (PS) and later the Intersecting Storage Rings (ISR). The group would later benefit from CERN's agreement with the Soviet Union, signed in 1967, to go to the world's highest-energy accelerator of its day at Protvino, near Moscow.

A Tale of Two Machines

Herwig's second stay at CERN coincided with a curious, yet vitally important period in the laboratory's history. By the mid-1960s, there were competing ideas as to what CERN's next major facility should be. The engineers were pushing for a proton collider, the ISR, which would be able to generate collision energies much higher than a fixed-target machine like the PS. But the physicists were worried that a collider would not produce enough collisions to do meaningful physics. Nobody had ever built one before, and to some it looked like a risky route to follow. They wanted to play safe, and were advocating a larger version of the PS, a super proton synchrotron, instead. By 1964, however, CERN's Director-General, Vikki Weiskopf, was convinced that a collider would work, and he set about persuading the CERN council to approve the project, while also presenting parallel plans for a 300 GeV proton synchrotron. His strategy was to get both machines approved, with the ISR coming first.

It was a strategy that paid off, and the long-term consequences are still playing out. The ISR came on-stream as the world's first hadron collider in January 1971, with the Super Proton Synchrotron (SPS) following five years later. By this time, there was no doubt that a hadron collider could provide enough collisions for physics: working with the ISR had taught CERN's scientists and users much about operating such a

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Fig. 6.1 Herwig giving an interview on succeeding Peter Preiswerk as Head of CERN's Nuclear Physics Division in 1970 (©CERN, All rights reserved)

machine, and building collider detectors. In 1976, just as the SPS started running, one such scientist made a bold proposal to convert it into a collider.

Carlo Rubbia argued that by doing so, experiments would be able to provide definitive evidence for a theory developed in the 1960s by Sheldon Glashow, Abdus Salam and Steven Weinberg that brought the electromagnetic and weak forces of nature together in a single theoretical framework. The electroweak theory required the existence of heavy force-carrying particles, labelled W and Z, and although evidence had been found for the Z by the Gargamelle experiment at the PS in 1973, the particles themselves remained to be discovered.

CERN's big project for the future was to build a large electron–positron collider (LEP) as a W and Z factory that would put electroweak theory to the test, but Rubbia saw a way to find the W and Z particles sooner. Converting the SPS to a collider was not trivial, but it was nevertheless easier than building a collider from scratch.

As a proton–proton collider, the ISR consisted of two rings, as its name suggests, so that two beams of protons could be made to circulate in opposite directions and collide at the intersection points. To turn the SPS into a collider, a different approach would be needed, as the SPS is just a single ring. The solution was to turn it into a proton–antiproton collider in which protons and antiprotons could be made to circulate in opposite directions inside the same magnetic ring. That required the construction of a facility to make and store antiprotons in sufficient quantities to make a beam.

In 1981, the SPS started to run as a collider, with Rubbia at the helm of one of its two experiments, known as UA1. Two years later, the discovery of W and Z particles was announced by the SPS collider's experiments, and the following year, Rubbia collected the Nobel Prize for Physics along with engineer Simon van der Meer, who had made hadron colliders possible through his development of a technique used to collect and marshal beams of antiprotons. The ISR was decommissioned in 1983, but it had changed the course of physics forever.

An Offer Too Good to Refuse—Back to Hamburg

When Herwig arrived at CERN in 1970 it was the year before the ISR started up, and SPS construction was well underway, coordinated from a new laboratory in France, just a few kilometres from the original CERN site in Switzerland. At the end of the year, CERN Director-General Bernard Gregory's mandate came to an end, and he was replaced by two Directors-General, Willibald Jentschke, who had been recruited from DESY, to run the original CERN laboratory, which was now known as Lab I, with John Adams in charge of Lab II and the SPS.

Jentschke's move meant that there was a vacancy at DESY, and in 1973, Herwig was invited to fill it. "I received a letter from Hamburg, and I remember it was a weekend," recalled Herwig. "My son had just got back from skiing in the French Alps and he laughed when I told him. He'd been up at 3000 metres, and the highest hill in Hamburg is just 100 m above sea level. There's a big difference between Geneva and the plains of northern Germany." Nevertheless, the offer was too good to refuse, and the Schoppers were soon on the move. Part of Jentschke's legacy was that as a national laboratory, DESY was independent of the university, so the post Herwig was offered was a dual one: the chair of the DESY directorate and a full professorship at the university. It was an arrangement that was right up his street.

Unorthodox housing arrangements were a trademark of Schopper family moves and the move to Hamburg was no different. The government of Hamburg had offered them a parcel of land, but there was no house on it, so while one was being built, they moved into the DESY guesthouse. "I rented two apartments in the guest house on different floors, and our dog, a collie, had to learn to move from one to the other one by taking the elevator. Another problem was that by this time we had a lot of furniture. I had a grand piano, and these apartments were too small." Luckily for the Schoppers, DESY had a lot of storage space, and another Jentschke legacy even provided an ideal solution for the piano. "Jenschke had insisted on having a very large office, and there was enough space in it for my grand piano. For my first two years at DESY I had an office with a grand piano and I could play it in the evenings."

Fig. 6.2 Herwig attends a lecture in the CERN Auditorium in 1971. Director-General Bernard Gregory is seated two places to his right ()

DORIS: A Collider, not a Girl

Herwig took over from Wolfgang Paul, who had stepped in on a temporary basis when Jentschke had left. He inherited an ambitious project that had been initiated by Jentschke in the 1960s: an electron–positron collider called DORIS, which stands for *Doppel-Ring Speicher* (double-ring store). With Europe's big laboratory CERN following an exclusively proton route and building the ISR and SPS, Jentschke had chosen a complementary path for Germany's new national laboratory. "DORIS was a collider system of two rings," Herwig explained, "the idea was that it could collide electrons with electrons. Most lepton colliders collide negatively charged electrons with their antiparticles, positrons, which have a positive electric charge. Because of their opposite charges the two kinds of particles can orbit in the same magnetic ring in opposite directions, but the downside is that it's hard to get strong positron currents since the positrons have to be created in a separate machine. DORIS's two rings avoided this problem and as well as being able to generate a high number of collisions leading to higher precision results, the expectation was that DORIS would be able to get different information than colliding electrons with positrons.

Fig. 6.3 Five Chairs of the DESY directorate. From left to right, Herwig Schopper (1973–1980), Wolfgang Paul (1971–1972), Willilbald Jentschke (1959–1970), Volker Soergel (1981–1993) and Bjørn Wiik (1993–1999) (©DESY, All rights reserved)

In theoretical terms, in electron–electron collisions the normal Coulomb interaction is at play, whereas in electron–positron collisions the particles can also interact by annihilating each other and then producing new particles. This allows interactions due to the electromagnetic force to be separated from those due to the weak force. In the end, however, since DORIS produced enough collisions in electron–positron mode, it was operated mostly in this way."

Herwig recounts a tale that shows how far the field has come since the early days of colliders. "When Jenschke started to discuss the idea for DORIS, he asked all the big theoretical physicists at DESY like Harry Lehmann and Kurt Symanzik what would be the highest useful energy for an electron–electron or electron–positron collider," he recalled. "Believe it or not, their answer was 2 GeV." The theorists based their argument on the fact that the cross-section for the collision of point-like particles, such as electrons and positrons, goes down with the square of the collision energy, so the higher the energy, the lower the number of collisions. In addition, all form factors for the production of non-point-like particles are smaller than one and so they thought that above 2 GeV, there would be so few collisions as to make physics research impossible. "But Jentschke," said Herwig, "being an experienced experimentalist, thought that nature would be more imaginative than the theorists, and planned for a higher energy machine. In an electron storage ring, the magnet system is not the most costly system, it is rather the high-frequency system that accelerates the particles. The reason is that the highest energy achievable increases linearly with the radius of the machine in a way that is not so dramatic, but the losses due to the emitted synchrotron radiation go up with the fourth power of the energy."

Jentschke decided to go for an energy of 5 GeV, modest by today's standards—the highest energy electron–positron collider to date was CERN's LEP, which accelerated beams to over 100 GeV, and was built while Herwig was Director-General of CERN in the 1980s—but Jentschke's choice turned out to have important consequences for DESY, giving access to a range of new physics as the years went on. "It was a very wise decision," said Herwig, "it shows you should not always take the advice of experts at face value."

DORIS started up in 1974, the year that Herwig arrived, with a beam energy of 3.5 GeV, later upgraded to 5 GeV in 1978. There were two particle physics experiments, called PLUTO and DASP. A number of other experiments also made use of the synchrotron radiation that sapped the energy of the beams, but provided a rich seam of research potential in fields other than particle physics. DORIS would run until 2013, and for much of its life, it was used exclusively as a synchrotron radiation facility for experiments ranging from solid state physics to life science.

The Discovery of Charm

"At the beginning nothing very dramatic happened, nothing very surprising was found," says Herwig. "Then something completely unexpected happened. There was a young physicist, Samuel Ting, who later became a professor at MIT. He had worked at DESY for several years in the 60s, and had a good feeling for where new physics could be discovered. At that time there were theories predicting new kinds of particles, which we now call charm particles. These theories could predict most of the properties of such particles, but not their masses. Since it is the mass of a particle that determines the minimum energy required to produce it, according to Einstein's famous equation $E = mc^2$, that made them rather hard to look for. We had no idea how heavy these new particles would be, which meant that to look for them you would have to scan through a wide range of energy, which is rather tedious with an electron–positron or electron–electron collider. Ting realised that he could do an experiment covering a wide band of energy with a proton machine, so he decided to spend some time at the Brookhaven National Laboratory in the US where they had a proton machine with sufficient energy to look for these charm particles, and indeed he found them there. Almost at the same time, they were detected at Stanford by a team led by Burton Richter."

This discovery became known as the November revolution in physics, because it triggered a chain of events that would reshape our view of the structure of matter, and set the direction for particle physics for many years to come. The teams led by Ting at Brookhaven and by Richter at Stanford had discovered a particle that is unique in that it had a double-barrelled name, the J/Psi. J resembles the Chinese character for Ting's name, while Psi was the name given by the Stanford Linear Accelerator

Centre (SLAC) team, because tracks left by the decaying particle resemble the Greek character. “Ting’s and Richter’s papers were published in the same journal side by side,” said Herwig. “However, there were rumours that Ting’s first results leaked out, giving Richter a hint at which energy to look at, which would have made things easier since Stanford would then have had to scan only a small energy region. There’s no doubt that both deserved the Nobel Prize since such a fundamental discovery needs a confirmation by two independent experiments.”

The J/Psi is a meson, a particle consisting of a quark and an antiquark. Before its discovery, only three types of quarks were known: up quarks and down quarks, which group together in threes to make up the protons and neutrons of ordinary matter, and strange quarks, which had made their presence known in the cosmic radiation constantly bombarding us from space. Theorists had been speculating about the existence of a fourth quark since the 1960s, but in 1970 Sheldon Glashow, John Iliopoulos and Luciano Maiani published a compelling paper that required the existence of a such a particle.

The J/Psi consists of a charm quark and an anticharm quark, and its discovery was effectively the experimental foundation stone of the Standard Model of particle physics. It won the Nobel Prize for Richter and Ting in 1976—this time, the experimentalists reaped the reward, while the theorists who predicted the new particle went empty handed, although Glashow would go on to receive the honour three years later.

Particle physics abounds with stories of scientists who could have discovered the J/Psi if only they had been looking in the right place. Apart from the machines at Brookhaven and Stanford, there were several others in the world that had the required energy, including DORIS at DESY and the ISR at CERN. “CERN could have detected the J/Psi but the guidance by theory was too limited,” said Herwig. “At CERN it was mainly collisions in the forward direction that were considered to be of interest, but to detect a new particle produced at its threshold energy, you need to look for particles coming out at large angles. In the first round of experiments at the ISR, nobody had a detector at large angles: they were only installed in the second generation and they immediately saw the J/Psi and the gluon. It was a pity that these were missed. Lesson: do not believe too much in theory.”

Once the discovery had been made, however, experiments at DORIS started to study the new particle, and it was then that Jentschke’s hunch to overrule his theorists really paid off. Although proton machines are good for discovery, electron machines are typically the machines of choice for precision physics, and PLUTO and DASP were in for a rich harvest, competing, and collaborating closely with Richter’s team at Stanford. “The mass of this new particle was just in the mass range accessible by the DORIS ring,” said Herwig, “so when we learned about that, the DORIS experiments immediately jumped on it and started to look for the J/Psi. During the first years I spent at DESY, the most interesting experiments were done with DORIS when they were investigating this newly discovered family of charm particles.”

The J/Psi particle is a charm–anticharm pair with parallel spins adding up to a total spin of one, but the theory predicted that charm quarks should also pair with opposite spins giving a total spin of zero. “The first major success of the DORIS experiments was that they could discover a new particle of the charm family, the so-called η_c (eta sub-c) particle, along with other charm-quark-containing mesons in which the charm quarks are paired with other kinds of quark and antiquark," explained Herwig. "These were very fruitful years, and there was healthy and friendly competition with SLAC, with a lot of data being confirmed mutually. To make the quark model credible, it was necessary to have consistent experimental results from several experiments."

Charm physics turned out to be just the start for DESY, with DORIS putting Germany's national lab for particle physics firmly on the international map. However, it was not long before another group of physicists in the US, this time led by Leon Lederman at Fermilab, was to discover a fifth type of quark. First predicted in 1973 by Japanese theorists, Makoto Kobayashi and Toshihide Maskawa, the bottom quark made its appearance in the form of the upsilon, discovered in 1977.

A playful sense of humour seems to surround everything that Lederman did. When his book about the Higgs boson, The God Particle, appeared, he said the title was his publisher's idea. He'd wanted to call it the Goddam Particle because it was so hard to find. Lederman had originally announced the discovery of the upsilon in 1976, but the announcement turned out to be premature—what had appeared to be a new particle was just an illusion, and thereafter, the initial discovery came to be known as the Oops-Leon, leaving upsilon for the real particle.

By the time the bottom quark made its appearance at Fermilab, DORIS was running at 5 GeV per beam, enough to produce upsilons abundantly. This allowed the DORIS experiments to clarify Lederman's discovery once and for all. "The mass resolution at Fermilab was bad," explained Herwig. "They discovered a peak that was relatively wide, so there was a suspicion it was not one particle but several with similar masses. A few weeks after the discovery at Fermilab, DORIS showed that the big peak at Fermilab was not one particle but in reality, three with slightly different masses that DORIS could resolve beautifully. DORIS showed for the first time that there was a whole family of B particles, as predicted."

Another Broken Symmetry—CP

Kobayashi and Maskawa had predicted the bottom quark in a theoretical answer to an experimental conundrum. Back in the 1950s the world had been introduced to the importance of symmetry, and in particular the way that nature can subtly break symmetry, by Lee and Yang when they proposed parity violation in beta decays, as well as by Salam, as Herwig discovered at Harwell in 1956 (see Chap. 5). When Herwig learned this, it changed the course of his career, leading him to publish one of the first experimental verifications of parity violation.

The notion of symmetry has profound consequences for our understanding of nature, with broken symmetries turning out to be one of the most important things in shaping the universe as we know it. The drama of parity violation, denoted by the letter P, had revealed that particle–antiparticle symmetry, denoted by a C, for charge conjugation, was also broken. However, the combination of charge and parity symmetries, CP, was considered to be sacrosanct. In other words, any particle interaction should be indistinguishable from the mirror image of that interaction in which the particles are also swapped for their antiparticles. While each symmetry could be broken individually, together they would be strictly conserved.

Another surprise was, nevertheless, waiting. Although not predicted by theory, it soon turned out that the combined CP symmetry is also violated, although not to the maximum degree possible, like C and P separately, but just a little bit. When this was demonstrated in 1964 by James Cronin and Val Fitch, it really upset the applecart of fundamental physics: it was a full decade before Kobayashi and Maskawa proposed their viable explanation for CP violation, along with the prediction of the bottom quark.

This time, both the theorists and the experimentalists were recognised with the award of a Nobel Prize. Cronin and Fitch received theirs in 1980, with Kobayashi and Maskawa having to wait until 2008 for the honour. As for Lederman, he received a Nobel Prize in 1988, but for work conducted earlier into neutrino physics.

DORIS's Last Particle Physics Hurrah!

DORIS's successes emboldened Herwig to plan for a bigger machine at DESY. It would be another electron–positron collider complementary to the big proton machines at CERN, and it would be known as PETRA. When it came on stream in 1978, most of the particle physicists moved to the more powerful machine, but DORIS still had one more particle physics trick up its sleeve. "I thought that it would be a pity not to continue to use DORIS for particle physics, so I convinced one of my former Ph.D. students from Karlsruhe, Walter Schmidt-Parzefall, to start a new collaboration and propose a new detector for DORIS. I promised him my full support as DESY director and after some hesitation he agreed. He managed to bring together a group of physicists and against most people's expectations this late experiment at DORIS produced a great result." Schmidt-Parzefall's collaboration consisted of groups from Russia, Germany, the United States and Sweden, giving rise to the acronym, ARGUS, and they were later joined by groups from Canada and Yugoslavia. Construction began in 1979, and the experiment ran from 1982 to 1992. The big result came in 1987. "ARGUS was the first place where the conversion of a B-meson into its antiparticle, an anti-B-meson, was observed," explained Herwig. "From these so-called B-oscillations one could conclude that it was possible to convert the bottom quark into a different quark. This was one of the most important results obtained at DESY and it came from a facility that was considered as obsolete by many scientists. From this ARGUS data one could also conclude that the as yet undiscovered sixth quark—the top quark—had to possess a huge mass, much higher than previously thought." The top was eventually discovered at Fermilab in 1995, with a mass of over 172 GeV/c^2, about 170 times heavier than a proton.

From DORIS to PETRA

Herwig was not alone in his ambition to build a big electron–positron collider. In the UK, the Rutherford Laboratory had plans for a similar machine, and at Stanford, there were plans to build bending arcs at the end of the two-mile Stanford linear accelerator to turn it into an electron–positron collider. Herwig was fortunate that his predecessor, Wolfgang Paul, had hired one of the foremost accelerator builders of his time, Gustav-Adolf Voss, who'd been working in the States on the Cambridge electron accelerator, a Harvard/MIT project that evolved under his guidance into a colliding beam electron–positron storage ring. Voss would go on to play a significant role at a later stage in Herwig's life, as a pioneer of the SESAME Laboratory in Jordan, of which Herwig was the first president.

"With him we discussed what the next machine at DESY could be," recalled Herwig, "and after some discussions, and taking into account the possible cost and the available size of the site, we came up with a proposal to build an electron–positron machine with a maximum energy of about 20 GeV." If successful, it would be the largest facility of its kind on the world. They named the project the *Positron–Elektron Tandem Ring Anlage* (positron–electron tandem ring facility), PETRA. "I decided to continue the tradition of giving DESY's machines female names," recalled Herwig, "a sign of the times, I suppose, since PETRA's positron injector, the Positron Injector Accelerator (PIA), followed suit. It was not easy to get PETRA approved, but I was optimistic after the success of DORIS."

Fig. 6.4 Chancellor Helmut Schmidt visited DESY on 11 March 1977 to take stock of progress on the PETRA storage ring (©DESY, All rights reserved)

Fig. 6.5 Herwig raises a toast on 27 January 1976 with German research and technology minister Hans Matthöfer on the occasion of the laying of the foundation stone for PETRA (©DESY, All rights reserved)

Synchrotron Radiation—A Valuable Spin-Off

While the approval process for PETRA was ongoing, and international discussions got underway to decide which facilities would get built, and which countries would support which others, DORIS set the direction for the laboratory that DESY would eventually evolve into. From the very beginning DESY had been a laboratory with a dual mission: fundamental physics using the synchrotron's particle beams, and a range of scientific applications using the so-called synchrotron radiation given off by the circulating beams.

"From the very beginning at DESY, the synchrotron radiation, which is a nuisance for particle physics experiments, was recognised as an important research tool in its own right," explained Herwig, "circulating electrons emit radiation with wavelengths ranging from infrared to hard x-rays, and several beamlines for this synchrotron light were installed at DORIS for solid state physics and biology experiments."

With the arrival of PETRA, DORIS's main focus was as a synchrotron light source, and in 1980 a special laboratory, HASYLAB, with more than 19 beamlines was opened for German and international researchers. "Christoph Kunz, Ernst Koch and Ruprecht Haensel, who later became director of the European Synchrotron Radiation Facility in Grenoble were among the key people to promote synchrotron radiation science at DESY," recalled Herwig. "I also signed an agreement with the Director-General of the European Molecular Biology Organization, John Kendrew, to install the organisation's first outstation at DESY." Over time, DESY's main focus would evolve from particle physics to synchrotron light source science, with PETRA itself becoming one of the world's most prominent synchrotron light sources and a powerful example of technology developed for particle physics serving other disciplines of science.

This, however, was not the only time that Kendrew's path would cross with that of Herwig, and the second time the circumstances were not so happy. A decade on, science funding in the UK was under considerable pressure. A committee was established to examine the country's involvement in particle physics in general, and in CERN in particular. The now-ennobled Sir John Kendrew was the chair. The committee recommended a 25% reduction in the UK's contribution to the laboratory, or if that proved not to be possible, complete withdrawal from CERN. This all happened in the middle of Herwig's tenure as Director-General (see Chap. 7).

The Electron Collider Race to 20 GeV

The course of true love never did run smooth, and so it was for the partnership that emerged between the Rutherford Laboratory and DESY over negotiations to build a 20 GeV electron–positron collider. "I must say I was under strong psychological pressure because first the British said that they urgently needed a new facility at the Rutherford lab," recalled Herwig, "but even more so because of SLAC."

The Rutherford Laboratory's 7 GeV proton synchrotron, Nimrod, which had started up in the early 1960s, and included a verification of Cronin and Fitch's observation of CP violation among its accolades, was reaching the end of its life. At Stanford, Pief Panofsky, the founding director of SLAC, was still at the helm. "Panofsky and I we were friends, we talked very often together," recalled Herwig. "He told me, 'Look, you are crazy to try to do something like that at DESY because we will do it faster and better—we have already the LINAC accelerator, it's much easier for us to add these two half circles and get collisions. You have to build a new tunnel, and we have much more experience than you, so our machine will be finished before your machine, and we'll do all the exiting physics before you can.' My answer was to tell my friend that we'd accept the challenge and compete."

PETRA required approval from both the federal government and the State of Hamburg. "I managed to get approval in an incredibly short time, a matter of a few months, thanks to the Federal Research Minister at that time," said Herwig. "His name was Hans Matthöfer, and I must say I have met and worked with many research ministers in my life, both in Germany and other countries, but he was one of the best. Although, and perhaps because he was not a scientist, he was prepared to listen to the advice of scientists, and he developed a good feeling for the quality of proposals and the people who presented them. In addition, he came from the trade union, he was a union man, and that gave him a very strong position in the Federal Cabinet to push through decisions and get PETRA approved."

Fig. 6.6 When PETRA was inaugurated in 1979, Germany's President, Walter Scheel (front) was in attendance, accompanied by research and technology minister, Volker Hauff, who had succeeded Matthöfer in 1978 (©DESY, All rights reserved)

Matthöher belonged to the Social Democratic Party, and the fact that the State of Hamburg also had a Social Democratic government at the time did no harm to Herwig's cause. "The Federal Government felt an obligation to give special support the North German regions, which were a little bit neglected at the time compared to South German states like Bavaria."

Federal and state-level approval was necessary for PETRA to go ahead, but was not in itself sufficient. Herwig also needed the approval of the next layer of hierarchy. For DESY, that meant that the *Verwaltungsrat*, an administrative council whose members included representatives of the federal government and the Hanseatic City of Hamburg, also had to deliver a formal endorsement. "For many years the *Verwaltungsrat* was chaired by Günter Lehr, and Hermann Schunk," recalled Herwig. "Josef Rembser, who later became President of the CERN Council, was also involved. The three were consecutive Directors-General in the Ministry for Research, and made very important contributions to science, in particular to particle physics."

With PETRA approved in the autumn of 1976, the case for the Rutherford Laboratory's new facility was greatly weakened, and Nimrod was destined to be the last major domestic facility for particle physics in the UK. Although the laboratory still hosts a thriving particle physics community, its major on-site facilities are now in the area of lasers, light sources and spallation neutron science.

"To provide some consolation to our British colleagues, we invited them to visit DESY, and I proposed that we should establish a collaboration," said Herwig. "One evening we had dinner in one of the restaurants near the River Elbe, and over dinner I explained that the room we were dining in was usually used for marriage parties, so I said, 'I hope our meeting here will also symbolise a union between DESY and the Rutherford Laboratory,' but the director of the Rutherford Laboratory answered in somewhat bitter terms, so the marriage, unfortunately, was not to be." The British were still clearly smarting at the loss of what might have been.

PETRA was soon up and running. "Thanks mainly to Gus Voss and his colleagues, PETRA was built in a record time of two years and eight months, with 20% less budget than planned, and it came into operation in the autumn of 1978," said Herwig, "almost two years ahead of our competitors at SLAC." Herwig had beaten his old friend Panofsky.

Nimrod switched off in 1979, as the UK focused its efforts on facilities overseas, contributing to the programmes at CERN, SLAC, and DESY, while the Rutherford Laboratory explored pastures new. There may have been no marriage between DESY and the Rutherford Laboratory in the 1970s, but what emerged was a strong and successful international partnership between particle physics laboratories around the world. Competition was fierce, but collaboration more so: a hallmark of modern particle physics.

Physics at PETRA and the Discovery of the Gluon

The approval of PETRA put DESY firmly on course to becoming an international laboratory. Although international collaborations were already well-established at DESY, notably with the ARGUS detector at DORIS and the European Molecular Biology Organization's outpost, it was at PETRA that they firmly took hold. Each of PETRA's four interaction points hosted an experiment run by an international collaboration. "Four detectors were approved for PETRA in 1977 after the usual extensive discussions and evaluations in the appropriate international advisory committee," said Herwig. "They were all proposed and constructed by international teams of outstanding scientists." The experiments were named JADE, Mark J, CELLO and TASSO. JADE was a simple concatenation of Japan—Deutschland—England. Mark J was an experiment headed by Sam Ting, who returned to DESY after his Nobel-winning exploits at Brookhaven. The CELLO collaboration was a mainly Franco-German collaboration, while TASSO, the Two-Arm Spectrometer Solenoid, was led by the Norwegian Bjørn Wiik, who would later become DESY's director. When these four experiments were approved, it was agreed that PLUTO, after one last run at DORIS, could occupy one of PETRA's interaction points until the last of the four new detectors was ready to be installed.

PETRA collided its first beams in September 1978, with data taking starting in earnest in January of the following year at Mark J, PLUTO and TASSO, JADE having suffered damage in a pilot run and CELLO not yet being ready. "There were two main questions that we hoped to solve with PETRA, looking into an energy range where theorists were unable to make many predictions, but where we thought some gold might lie," said Herwig. "One was the search for the top quark, and I remember one day a very well-known German theorist came and told me, 'Look, I have a new theory, and I am sure that the mass of the top quark must be in the range of about 22 GeV.' PETRA was designed for 20 GeV, but the magnets were powerful enough to

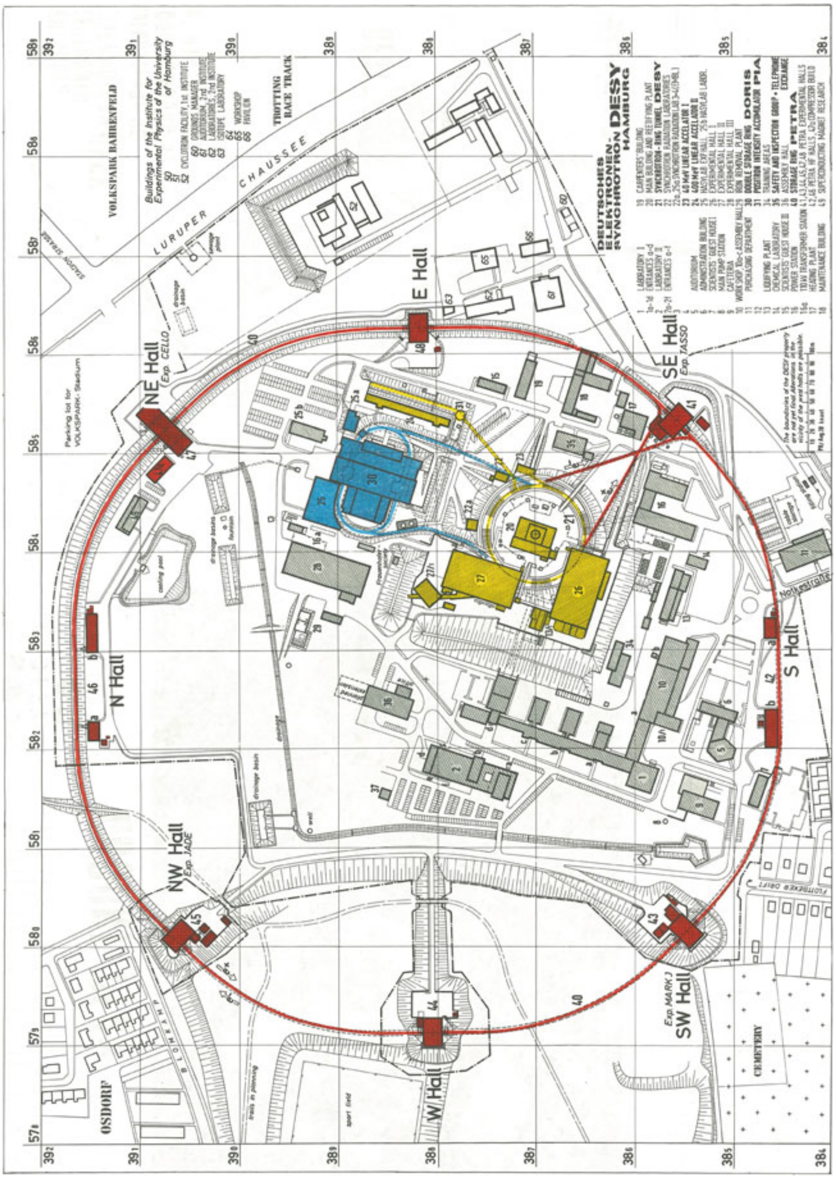

Fig. 6.7 A plan of the DESY laboratory showing the position of the PETRA ring in red (©DESY, All rights reserved)

handle higher energy beams if more accelerating cavities were added, so after some discussions with the committees, we increased the energy to 27 GeV, but there was no top quark to be seen, much to our disappointment. As we know now, the top quark is much, very much, heavier and was discovered many years later at Fermilab."

The second big hope for the PETRA experiments resulted in a major discovery in 1979. "The other burning topic at the time was the search for the carrier of the strong nuclear force, which is called the gluon because it is responsible for binding together the quarks, and consequently the constituents of the atomic nuclei, protons and neutrons, and hence guarantees the stability of matter," explained Herwig. "It seemed difficult to find, but there was a prediction that gluons would decay into three jets of particles, which would be an unmistakable signature for them. The gluon's mass was not fixed and so there was no particular energy range to search, but the consensus was that the best place to look would be at high energy because the individual jets would be easier to identify. The experiments started to look for the gluon."

When an electron and a positron collide, the collision can give rise to a quark and an antiquark, each of which cascades into a jet of particles emerging from the collision. The theoretical prediction that the PETRA experiments were looking for was the occasional emission of a gluon, which would lead to three jets of particles, not just two. In addition, all three jets would be in the same plane. As PETRA's energy was gradually ramped up, from 13 GeV initially then to 17 GeV, and finally by spring 1979 to 27 GeV, all the experiments were keenly scanning the data for three co-planar jets. "Each experiment had a different approach," explained Herwig, "each focusing on different properties of the gluon, but in the end all four found the gluon, with even PLUTO producing interesting gluon data. This, was a great success and a very happy event."

Happy though the particle physics community may have been at this momentous discovery, the question of who got there first was a matter of some contention. "There were some heated discussions, particularly between Mark J and TASSO, whose leaders were Sam Ting and Bjørn Wiik," recalled Herwig. "Both claimed that their experiment had seen the gluon a little bit earlier than the other. I followed these discussions closely, receiving reports almost daily. I think it was a futile fight: only the results of all four experiments together provided convincing evidence since the signatures were not so clear that one experiment alone could claim that they had established the existence of the gluon beyond any doubt." Over time, the community gave the discovery the recognition it deserved, with the European Physical Society devoting two awards to the discovery in 1995. One, the annual High Energy and Particle Physics Prize went to Paul Söding, Björn Wiik, Günther Wolf and Sau Lan Wu from the TASSO collaboration, while the second, a special one-off prize, honoured all four experiments.

"This discovery was a great success for DESY," remembered Herwig, "but later it also produced some disappointment. To understand how something could be so important, a bit contentious, and also disappointing at the same time, it's worth taking some time to understand the physics behind it." In quantum physics, the actions of nature are described by the exchange of force-carrying particles between particles of matter. There are four fundamental forces at work in the universe today, governing everything from the movement of stars and galaxies to the inner workings of atoms. They are gravity, electromagnetism, the weak nuclear force and the strong nuclear force. Gravity governs the large-scale behaviour of the universe, but it is the weakest of the forces by far. No verified quantum theory of gravity exists, and there are no techniques to study it at the particle level. The great success in this domain was the first observation of gravitational waves by the LIGO experiment in 2015.

Particle physics focuses on electromagnetism and the nuclear forces. Among the carriers, the photon is the best known. It not only transmits light but is also responsible for binding electrons to nuclei to form atoms, and atoms to each other to form more complex structures. The existence of the photon was established at the beginning of the last century.

The weak nuclear interaction is necessary to understand nuclear beta decay and is the driving force behind energy production in stars. It is carried by electrically neutral Z particles, a bit like heavy photons, and charged W particles. The discovery of these particles at CERN was announced in 1983. The strong nuclear force, which confines quarks to form protons and neutrons, and binds protons and neutrons into nuclei, is carried by the gluon.

The overall picture of particles and their interactions is called the Standard Model, and it has one more ingredient: the Brout-Englert–Higgs (BEH) mechanism, which accounts for the masses of many of the fundamental particles. Its existence was confirmed at CERN by the 2012 discovery of a particle that carries the name of Peter Higgs.

At the time the gluon was discovered at DESY, this picture was still being painstakingly pieced together, and each new particle discovery provided an important part of the puzzle. "The discovery of particles had been a rich source of Nobel Prizes," explained Herwig, "so there were hopes that this would be the case for the discovery of the gluon, but that didn't happen." When two CERN scientists, Carlo Rubbia and Simon van der Meer, were awarded the Nobel Prize in 1984 for their contributions to the discovery of W and Z particles, the feeling of disappointment at DESY must have been very keenly felt. "The problem was that the gluon was discovered by several experiments involving too many outstanding scientists whereas the Nobel Prize can only be given to three people," said Herwig. "That seems unjust in my opinion because it doesn't do justice to experiments carried out in collaborations. The Nobel Committee's three-person rule is more easily fulfilled by theorists than experimentalists."

In recent physics history, Rubbia and van der Meer have been the exceptions: it's rare for experimentalists to receive the Nobel Prize. The discovery of the gluon was crowned with a Nobel Prize: for the theorists David Gross, Frank Wilczek and David Politzer who pioneered the theory of strong interactions, quantum chromodynamics in the 1970s. They received the call to Stockholm in 2004, curiously one year before the EPS rewarded the DESY experiments with its awards.

When the ATLAS and CMS experiments at CERN announced the long-anticipated discovery of the Higgs particle in 2012, it was a similar story. Two large experiments taking data at the world's most powerful particle accelerator and relying on powerful computing infrastructures were necessary to make the discovery. Thousands of people contributed to the effort, yet the Nobel Prize in 2013 was awarded to two theorists, François Englert and Peter Higgs, Robert Brout having passed away before he could enjoy the experimental confirmation of the BEH mechanism. "There's no doubt that the theorists deserve their Nobel Prizes," said Herwig, "physics requires both experiment and theory, but the three-person policy gives the wrong picture about the nature of research, particularly to young people. I know the Nobel Committee is aware of this problem, but there seems to be no easy solution."

A New Lease of Life for PETRA

The discovery of the gluon was the undoubted highlight of the PETRA particle physics programme, although the PETRA experiments continued to produce good physics up to 1990, when PETRA was repurposed as an injector for a new machine, HERA, the *Hadron-Elektron Ring Anlage* (hadron electron ring facility), and as a light source, continuing the tradition established by DORIS. Later, after the shutdown of HERA, PETRA became one of the world's best facilities for synchrotron radiation research. This transition came long after Herwig's watch at DESY and is the source of some amusement to him today. "I was always very much in favour of using the electron machines as sources of synchrotron light, since my original research was not in particle physics or nuclear physics, but was more general so I understood the people wanting to use synchrotron radiation," he explained, "but when I asked the synchrotron radiation people whether they would be interested in using PETRA for their experiments, their answer was: 'Only a stupid high-energy physicist could ask such a question, because if you shot such energetic photons at molecules, they would destroy them.' The characteristic photon energy of the synchrotron radiation with PETRA running at 20 GeV was around 120–150 keV, which was felt to be much too high for atomic or molecular physics. So I did not succeed in attracting any of the synchrotron people to PETRA. That was one of my largest disappointments and surprises at the same time because nowadays, many years later, PETRA has become one of the major and best research instruments in the world, not for particle physics but for biology and solid-state physics because it turned out that PETRA is one of the best machines for synchrotron light if you run it much below its maximum energy. It turns out if a machine has a large circumference like PETRA, the synchrotron light you get is much better concentrated than in a machine with a smaller radius. It's the so-called emittance of the beam that is decisive—the larger the radius, the lower the emittance and the brighter the synchrotron light. After its successful life as a machine for particle physics, PETRA has become a fantastic machine for all kinds of research, and in particular for biology. There's a huge new experimental area for users, and the European Molecular Biology Organization has extended its outpost at DESY. You never know what might become of these old-fashioned facilities."

HERA—A Legacy

Herwig's time at DESY came to an end in 1980, when he received the call to become Director-General of CERN from January 1981. "Before I had the offer to come to CERN, we had discussed a new project to follow the success of PETRA, and this project was the electron–proton collider, HERA, another female name for another DESY machine, continuing the tradition set by DORIS. In the directorate, mostly

Fig. 6.8 Three Directors-General. Taken at CERN in April 1980, this picture shows Director-General-elect Herwig standing between John Adams, Executive Director-General (left) and Léon van Hove, Research Director-General. The fact that there were two DGs is a legacy of CERN being run as two laboratories at the end of the 1970s (©CERN, All rights reserved)

working with Guss Voss, we had worked out a concept for the project and I presented it to DESY's *Verwaltungsrat* on 6 December 1979. Of course, HERA was realised by my successors, and it was Volker Soergel who promoted it and got it approved. But the concept of HERA was developed when I was still at DESY. So apart from getting PETRA approved and built, I am somewhat proud that during my time, DESY was converted from a national facility to an international laboratory. Of course, formally it's still a German laboratory, but I think the users from the outside coming from all over the world feel completely at home there."

In His Own Words

The Chinese at DESY

"One day, I was sitting in my office and the telephone rang. At the other end of the line was Sam Ting. 'Sam,' I said, 'how are you and where are you? Are you in Beijing?' 'I'm sitting in the office of Deng Xiaoping,' came the reply. I said, 'Okay. What is the matter?' He replied, 'Well, I'm discussing with him whether he would be interested to send for the first time Chinese scientists to western countries.' This happened in 1978 soon after the end of the Cultural Revolution at a time when contacts between China and western countries did not exist. So I said, 'Okay. Why not? How many people do you think they would like to send?' He consulted Deng Xiaoping and came back with: 'What about a hundred?' 'A hundred is maybe a little bit too many,' I said. 'Why don't we start with a dozen?' They agreed: 'Okay, we start with a dozen.'

Based on this telephone conversation a collaboration started between China and DESY, and indeed, it was the first time scientists came to a western country from the People's Republic. The first arrived in January 1978 and It was really very moving when 12 people arrived in April 1979, and they had to learn how to behave in a modern technically developed country. At that time in China there were practically no cars. The main means of moving around was bicycles. In Beijing, the roads were crowded by bicycles, but no cars. So when these 12 people came from Institute of High Energy Physics (IHEP) in Beijing, they had to learn how to cross the busy roads in Hamburg and not to be runover by cars. Sam Ting had a colleague at that time, Susan Marks, who he later married. Susan became a kind of mother hen to the Chinese group, teaching them how to behave, how to cross the roads, how to do shopping and things like that. It was amusing to see her sometimes walking around DESY or outside being followed by a line of Chinese people like a group of young chicks following their mother. Over the following years physicists came and went. All of them, of course, had been selected before they came to Hamburg. All were excellent scientists. The leader of the first group was Tang Xiaowei and there were also Zhen Zhi Peng and Chen Hesheng, who both became directors of IHEP. Many of those who had spent some time at DESY participated later in the Mark J experiment at DESY, or the L3 experiment at CERN, both of which were headed by Sam. Some

Fig. 6.9 Herwig with a Chinese delegation at DESY in 1978. Sam Ting is second from right, seated next to his future wife Susan (©DESY, All rights reserved)

went on to outstanding careers going on to fill important posts in science or policy in China. I became friends with some of them and met them quite often later when I visited China.

Later, when I became Director-General at CERN, and Sam Ting followed me to CERN, he proposed the L3 experiment for the LEP machine there. That was the first time that Chinese scientists from Taiwan came to a foreign country, and that the Chinese of Taiwan and the People's Republic were allowed to work together in a common experiment. Of course, there was no problem between the physicists, but this collaboration again had to get approval from the highest authorities in Beijing and Taipei. So it's a beautiful example of how fundamental research can contribute to science for peace, creating better relations between governments."

Acknowledgements

"Since DESY was such an important part of my career, I can't end this chapter without acknowledging some of the outstanding people I worked with there. The overall scientific success of DESY depended on not only the original synchrotron and the colliders that followed, but also, of course, the experiments. Many scientists made important contributions and it is impossible to mention them all. The tendency in high energy physics is to emphasise the collaborative effort that is necessary, and names are often not mentioned at all, except in the original scientific publications. I have to follow this tradition also and I can mention only a small number of names, favouring those colleagues with whom I had regular day-to-day contact.

At the very beginning of DESY, Peter Stähelin and Martin Teucher, who had come with Jentschke from the USA, were essential. DESY has always had a cohort of leading scientists who are essential for the long-term success of the laboratory. Most of them served for a number of years as members of the directorate. Among them are the physicists Erich Lohrmann, Gustav Weber, Günther Wolf, Paul Söding, Johann Bienlein and Gerhard Horlitz.

From the technical side there is of course Guss Voss, as well as Donatus Degele and Hermann Kumpfert. The administration is often overlooked and always essential, and one person who defined it for many years was Heinz Berghaus followed by Senatsdirektor Richard Laude and later by Wolfram Schött who came from the research ministry at Bonn and we became friends. In various functions supporting the directorate were Wolfgang Grillo, Peter von Handel, Helmut Krech, and Gerhard Soehngen.

When you hold a prominent position, you need somebody to protect you from too many meeting requests, someone you can trust implicitly to represent you to see you: a *Chef de cabinet* as it is called today, but at that time the person who carried out this task was my secretary, Karin Schmöger who made my life bearable. Last but not least, I would like to acknowledge those who became my successors as chairs of the DESY directorate Volker Soergel, Bjørn Wiik, Albrecht Wagner and Helmut Dosch, the latter two of whom gave DESY a new direction in research.

During the construction of PETRA there were many discussions as to whether DESY should legally become an international laboratory. This did not happen, and DESY remained, at least officially, a national lab. However, the international participation in PETRA experiments was broad, and many scientists from all over the world contributed. An outstanding one is Sam Ting."

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