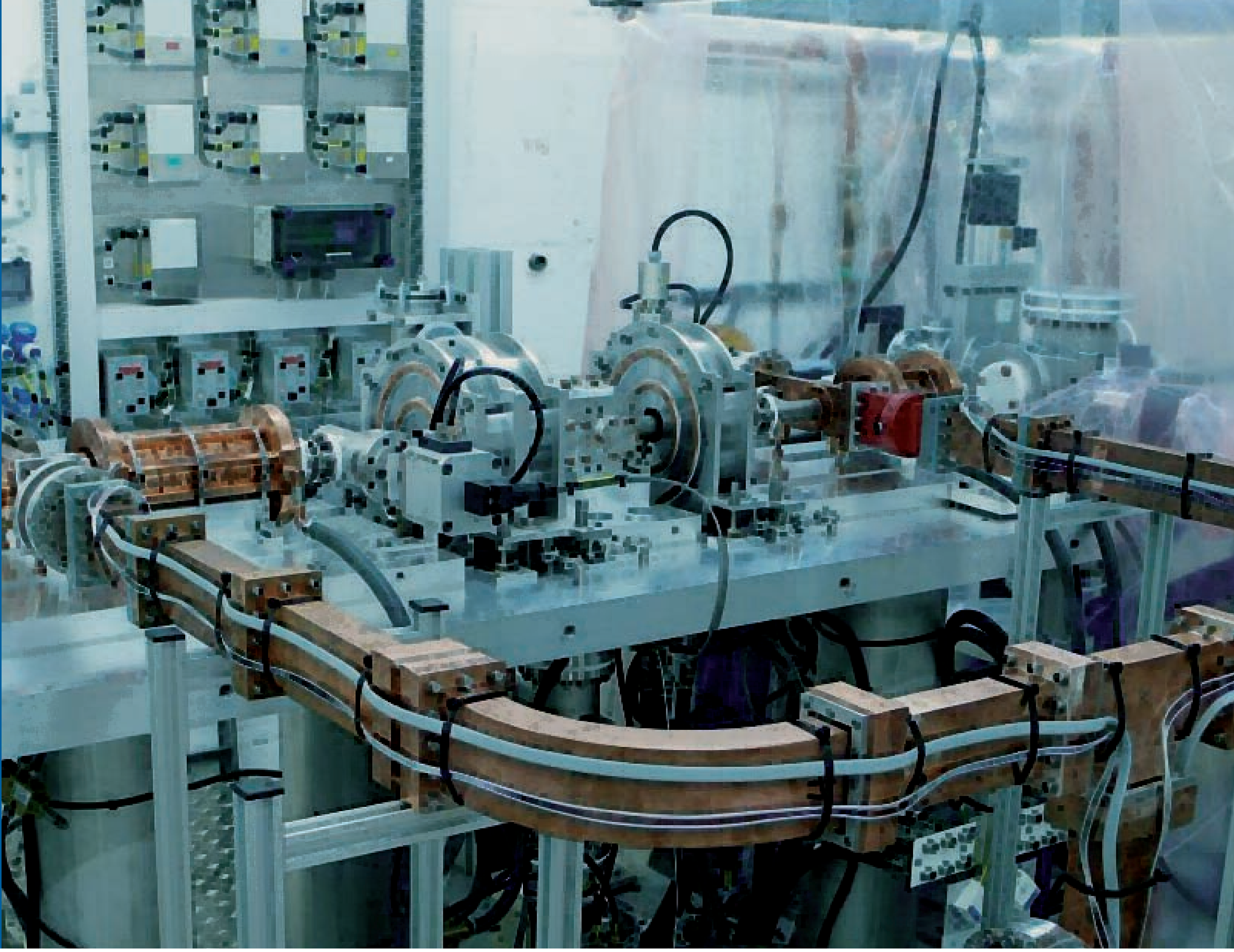
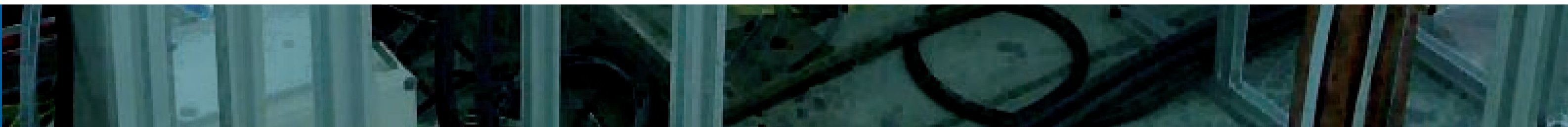


ACCELERATORS 2011.

Highlights and Annual Report

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association



Cover

REGAE, the newly built Relativistic Electron Gun for Atomic Exploration.

ACCELERATORS 2011.

Highlights and Annual Report

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The year 2011 at DESY.

Chairman's foreword

DESY and its accelerator facilities saw much progress in 2011. It is very gratifying to see how the smooth operation of our X-ray facilities DORIS III, PETRA III and FLASH is keeping DESY at the international forefront of world-leading photon science laboratories. I am most grateful to the accelerator division for providing our users with such an efficient and high-performance operation of our X-ray facilities.

The scientific output is indeed most impressive, and the international research community is continuing to perform top-level research in close collaboration with our scientists. With their extraordinary X-ray beam qualities and the unique instrumentations, the new facilities PETRA III and FLASH exert highly attractive forces on the international science community. FLASH II and the PETRA III extensions are already under construction and will soon offer additional and novel possibilities for research with super-brilliant X-ray light.

The construction of the European XFEL has made enormous progress. Thanks to a unique financial effort of the Russian–German collaboration, the European XFEL is being realized in the full scope of the Start Version, including the 17.5 GeV accelerator design mode. The 2.1-km-long accelerator tunnel was successfully completed in August 2011. All necessary preparations are currently being made to allow installation of the technical infrastructure to begin in May 2012. Around this time, we also expect the first production and testing of the 100 superconducting accelerator modules, the core elements of the linear accelerator. For that purpose, testing infrastructures have been successfully installed in the hall of the Accelerator Module Test Facility (AMTF). I am particularly grateful to Hans Weise and his team for the excellent work.

On a regional level, we have launched the Partnership for Innovation, Education and Research (PIER) together with the University of Hamburg. Four research fields (particle and astro-

Helmut Dosch giving a lecture at the Open Day and Science Night 2011

Recovering the TULA cutterhead on the European XFEL construction site DESY-Bahrenfeld on 22 August 2011

particle physics, photon science, nano science and structural biology) have been defined, enabling us to join forces in fostering common research projects and promoting young students through a joint graduate school. To achieve maximum synergy, the scope of PIER will be enlarged to better integrate accelerator R&D activities as well.

One highlight of activities by and for DESY has been the so-called Helmholtz Portfolio process, in which the Helmholtz centres have been striving to identify new topics that are of key relevance for our society and require the focused and strategic attention of the Helmholtz centres. Under the strong guidance of DESY, three key R&D areas have been identified and successfully implemented in the research field "Structure of Matter". One of them is the Accelerator Research and Development (ARD) initiative under the leadership of Reinhard Brinkmann. The ARD programme bundles the accelerator competences of the Helmholtz centres and integrates the accelerator activities carried out at universities. Joining all forces in accelerator development within the Helmholtz centres – but also beyond the Helmholtz Association, with the university groups – will strongly impact other disciplines, such as health and key technologies. The successful implementation and transformation of accelerator R&D into a research topic of its own under the new Helmholtz main programme "Matter and Technologies" in the upcoming third Helmholtz framework funding period (2015–2019) has been of highest relevance for DESY.

Cooperation agreement between DESY and the Middle East synchrotron radiation facility SESAME. From left: Sir Christopher Llewellyn Smith (President SESAME Council), Klaus Töpfer (Executive Director IASS), Helmut Dosch (Chairman of the DESY Board of Directors), Gretchen Kalonji (UNESCO) and Khaled Toukan (Director-General of SESAME and Minister for Energy and Mineral Resources, Jordan)

A unique event that DESY hosted in May 2011 was the international Symposium "Solar Energy for Science" under the auspices of UNESCO and chaired by Klaus Toepfer, former Under Secretary General of the United Nations and Energy Advisor to German Chancellor Angela Merkel. International key authorities from science, including Nobel laureates Carlo Rubbia and Walter Kohn, met with policy makers from Europe and the Middle East and North Africa (MENA) region to discuss a novel energy and science partnership between Europe and MENA, which aims to stimulate further scientific cooperation and promote renewable energies for a sustainable development around the Mediterranean basin. As a top-class international research laboratory, DESY was an ideal host and moderator for this event, which strived to build bridges between Europe and the MENA region.

I warmly thank all our accelerator experts at DESY for their impressive work in 2011.

Yours,
Helmut Dosch

Chairman of the DESY Board of Directors

Accelerators at DESY.

Introduction

The DESY accelerator division is looking back on a very fruitful and successful year 2011. User operation of the storage rings DORIS III and PETRA III and of the free-electron laser facility FLASH proceeded very efficiently with excellent performance. The large accelerator construction project for the European XFEL X-ray laser is coming into full swing. The Accelerator Research and Development (ARD) initiative was approved as a new programme by the Helmholtz Association. And with the start of commissioning of the Relativistic Electron Gun for Atomic Explorations (REGAE), the accelerator family at DESY got a new member.

For PETRA III, 2011 was the first full year of regular user operation. The machine has been running routinely with beam parameters as specified. It achieved an average availability very close to the goal of 95%, and even exceeded this goal over several weeks of operation in the later phase of the year. Our definition of availability is very strict: a beam loss of only 5% due to an interruption in the top-up mode is already counted as a failure. In parallel to the machine operation, the preparations for the extension of PETRA III with new beamlines, to be performed in 2013, are ongoing.

At DORIS III, the OLYMPUS particle physics experiment was installed and important first experience with the gas target cell was gained during routine operation runs for synchrotron radiation users. During machine studies, rapid and reliable switching between electrons and positrons was exercised successfully in the pre-accelerator chain – an important prerequisite for the efficient operation of OLYMPUS, which is scheduled for 2012.

FLASH was operated with a very satisfactory availability of 96% during user runs, with the exception of a two-week early termination of the final user run in autumn due to a fault in the injector gun RF window. The FLASH crew coped well with the wide diversity of user demands regarding photon wavelength, pulse length, number of electron bunches, etc. Yet further improvements in automated procedures at FLASH remain a challenge (and were one of the topics that spawned lively discussions at the FLASH operation seminar held in Grömitz in September 2011). During machine studies carried out together with colleagues from the International Linear Collider (ILC) collaboration, stable and reliable acceleration of long bunch trains with high intensity could be demonstrated – a result which is equally relevant for FLASH, the European XFEL and the ILC.

The construction work for the European XFEL facility reached yet another important milestone: in summer 2011, the 2.1-km-long tunnel for the superconducting linear accelerator (linac) was completed. It is now being prepared for installation of the technical infrastructure, which will begin in March 2012. The series production and testing of the 100 accelerator modules for the European XFEL linac will also start in 2012. Many colleagues at DESY and at the partner institutes in the European XFEL Accelerator Consortium have been very busy in 2011 to set up the complex and challenging procedures for the integration and assembly of the modules, which will take place at CEA Saclay near Paris. The modules will then be transported to DESY

for extensive tests at the Accelerator Module Test Facility (AMTF), where the testing of the individual superconducting cavities as well as the assembly and testing of RF components will also be carried out. In 2011, the installation of technical infrastructure in the AMTF hall was completed. The setup of cryogenic, RF and auxiliary equipment for the test stands is progressing. Many components for other subsystems of the accelerator complex were ordered from industry (e.g. RF systems) and the cost development shows that we are very well on track with our financial planning. At the PITZ photoinjector test facility at DESY, Zeuthen Site, yet another record was achieved on beam quality in 2011: the PITZ gun is at present the world's brightest electron source in terms of emittance for a given bunch charge.

The electron diffraction experiment REGAE saw its first beam in November 2011. This "relativistic femtosecond electron microscope" is being built in close cooperation with the Max Planck group of Prof. Dwayne Miller at the Center for Free-Electron Laser Science (CFEL). The S-band gun of REGAE produces low-charge, low-emittance electron bunches of a few MeV energy, which are ballistically compressed to a length of only a few femtoseconds. The REGAE beamline is presently being completed and first experiments are expected later in 2012. The REGAE beam is also an ideal probe for ultrahigh-gradient accelerating fields excited in a plasma by a high-peak-power laser – which brings me to another exciting activity.

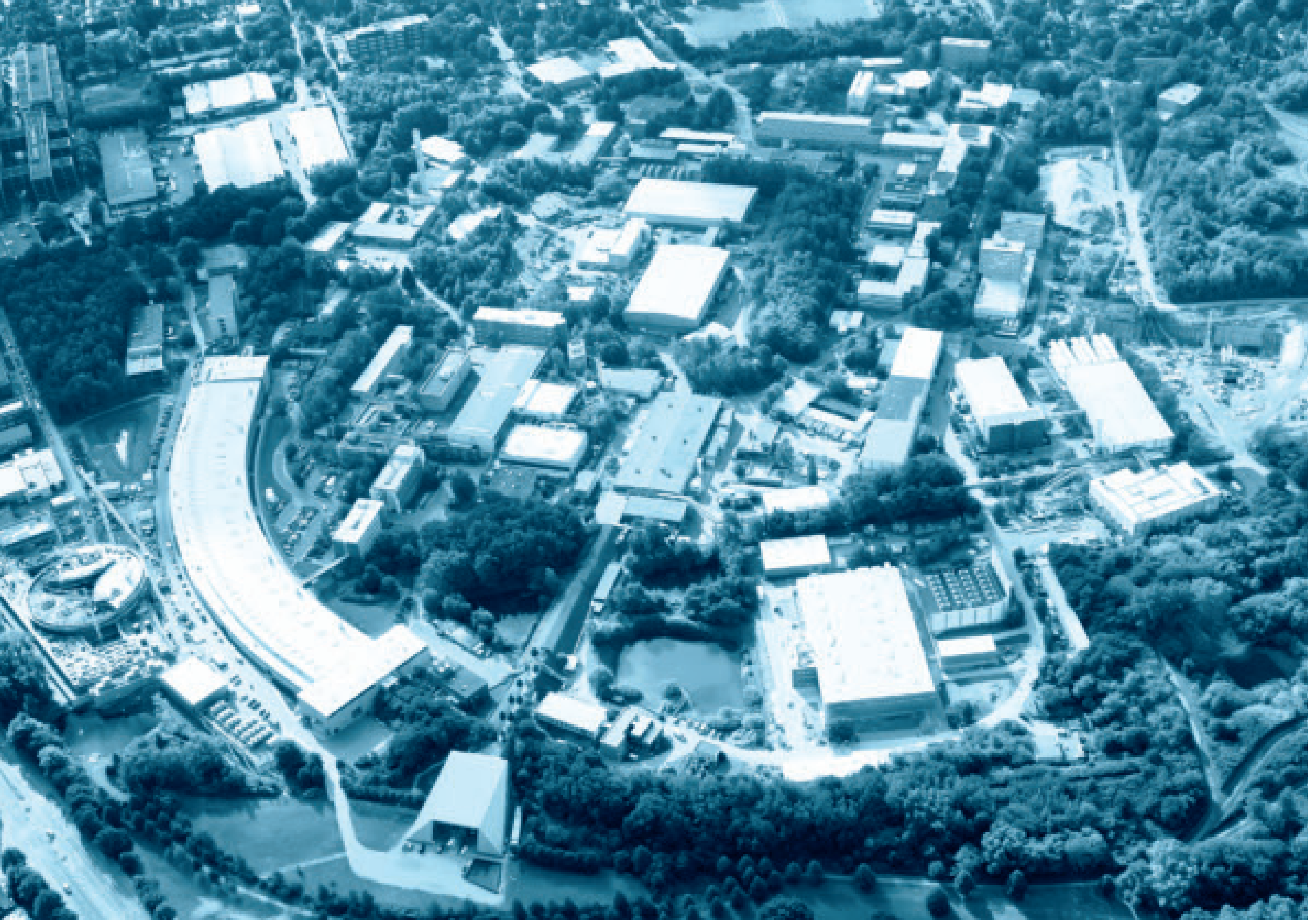
The new Accelerator Research and Development (ARD) programme was approved by the Helmholtz Association in June 2011 – a very satisfying success of an initiative which was launched in 2010 by six Helmholtz centres under the leadership of DESY. This programme brings additional funding to the laboratories dedicated to accelerator R&D, improves the networking between the labs, with universities and international research groups, and has the potential to attract more bright young people to the field of accelerator physics and technology. DESY is engaged in the research topics superconducting RF, femtosecond electron and photon beams and, as a topic very new to DESY, plasma wakefield acceleration.

This new Helmholtz development coincides very timely with a strengthening of the cooperation with Hamburg University, where two new professors (Brian Foster and Florian Grüner) were appointed in the field of accelerator physics. Accelerator physics and technology were also discussed very lively at the third round of the DESY accelerator ideas market in September 2011, a forum which was created in 2010 and serves as a platform for communication of new ideas, concepts and possible projects regarding accelerators in the widest sense.

I could only briefly touch on these topics in this short introduction – you will find much more information on the following pages. Enjoy the reading! ●

R. Brinkmann

Reinhard Brinkmann
Director of the Accelerator Division



News and events.

News and events.

A busy year 2011

March

First accelerator module delivered from Saclay

The first European XFEL accelerator module assembled at Saclay was delivered to DESY and unloaded in the hall of the Accelerator Module Test Facility (AMTF), where all cavities and accelerator modules of the later serial production will be tested under operating conditions before being installed inside the European XFEL tunnel.

Module PXFEL2_1 is unloaded in the AMTF hall.

Module PXFEL2_1 is a prototype for the future serial production. In summer 2010, after assembly and testing at DESY, it was transported to CEA Saclay, France, where all European XFEL accelerator modules will be mounted starting in 2012. Here, the prototype module was dis- and reassembled, except for the chain of eight superconducting cavities, to test the Saclay assembly lines and train the assembly staff.

At its return to DESY, the 7.5-tonne 12-metre module was unloaded from the truck with the AMTF hall crane. This was the first time the unloading took place under real-life conditions, with the components and facilities provided for the future series modules. PXFEL2_1 was placed on the first of three roller bearings which will later transport the modules on rails to their test benches. The roller bearings, installed just in time by the Russian Budker Institute, and the test benches' rail system were then submitted to a load test and calibrated. The next step was to test the technical features of the prototype module at the Cryo Module Test Bench (CMTB), while the assembly of the components for the modules' serial tests in the AMTF hall proceeded as planned.

April

Brazil's Minister of Science visits DESY and European XFEL

On 6 April, Brazil's Minister of Science and Technology, Aloízio Mercadante, visited DESY and the European XFEL. He came together with the director of the Brazilian Synchrotron Light Laboratory (LNLS), José Roque da Silva, on the occasion of the conclusion of the German–Brazilian Year of Science, Technology and Innovation.

The representatives from Brazil, the German Federal Ministry of Education and Research (BMBF) and the directors of DESY and the European XFEL GmbH summed up the collaboration that resulted from the Year of Science and discussed the possibilities of intensifying their cooperation in science and technology. During a tour of PETRA III and FLASH and a visit of the European XFEL construction site in Schenefeld, the Brazilian delegation took the opportunity to learn more about the research potential of these facilities.

Brazil is Germany's most important scientific partner in South America. With LNLS in Campinas, it operates the only synchrotron radiation source on the continent. Brazil plans the construction of a third-generation synchrotron radiation source and is also interested in the development of accelerator-based free-electron lasers.

Helmut Dosch, Aloízio Mercadante (Brazilian Minister of Science and Technology) and Massimo Altarelli (Managing Director European XFEL)

May

Humboldt Research Award for Richard Milner

Prof. Richard Gerard Milner from Massachusetts Institute of Technology (MIT) was honoured with a Humboldt Research Award granted by the Alexander von Humboldt Foundation. Richard Milner is the initiator and spokesman the OLYMPUS experiment at the DORIS III accelerator, which aims to accurately determine the form factors of the proton. The award offers him the possibility to stay at DESY for longer research periods during the preparation and data taking of the experiment.

Professor Richard Milner

Born in Ireland, Richard Milner graduated at California Institute of Technology (CalTech) and carried out research at MIT. From 1998 to 2006, he was director at the Bates Linear Accelerator Center, which operated the BLAST detector, the predecessor experiment of OLYMPUS. Milner currently heads the Laboratory for Nuclear Science at MIT.

DESY has played an important role in Milner's career. Milner is one of the founding fathers of the HERMES experiment at the HERA storage ring, which investigates the spin structure of the nucleon. From 2005 to 2009, he was a member of the DESY Physics Research Committee (PRC).

Cooperation agreement concluded in Brasília

In the presence of Germany's Federal President Christian Wulff and Brazil's President Dilma Rousseff, the three directors of DESY, the European XFEL and the Brazilian synchrotron laboratory LNLS signed an agreement on future cooperation on 5 May in Brasília.

From left: José Roque da Silva, Director of the Laboratório Nacional de Luz Síncrotron (LNLS) in Campinas, Brazil; Christian Wulff, President of the Federal Republic of Germany; Dilma Rousseff, President of the Federal Republic of Brazil; Helmut Dosch and Massimo Altarelli. (Photo: DWIH São Paulo)

On the occasion of the state visit of Federal President Christian Wulff, Brazil's President Dilma Roussef invited to a press conference in the presidential palace. In the course of this event, two research agreements were sealed, one of them between the Brazilian synchrotron laboratory LNLS, the European XFEL GmbH and DESY. In April, Brazil's research minister and the LNLS director had visited DESY and initiated the agreement.

Brazil intends to create 75 000 international scholarships in the coming years for university students, with 10 000 of them going to Germany. One of the first consequences of this trilateral agreement could thus be the admission of Brazilian students and junior scientists at DESY and the European XFEL.

DESY cooperates with SESAME

On 19 May, the directors of DESY and of the synchrotron radiation source SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East) in Jordan signed a cooperation agreement. In addition to the cooperation in the use of synchrotron radiation and accelerator technology, both laboratories stressed their intention to promote joint scientific projects in Europe and the Middle East and North Africa region, thus increasing the dialogue between these parts of the world. Moreover, an exchange of scientists and students is intended.

From left: Sir Christopher Llewellyn Smith (President SESAME Council), Klaus Töpfer (Executive Director IASS), Helmut Dosch (Chairman of the DESY Board of Directors), Gretchen Kalonji (UNESCO) and Khaled Toukan (Director-General of SESAME and Minister for Energy and Mineral Resources, Jordan)

DESY accelerator director Gustav-Adolf Voss and Herman Winick from the SLAC National Accelerator Laboratory came up with the idea of SESAME in 1997. They wanted to support the development of science in the Middle East with the installation of a dismantled German synchrotron in the region. SESAME was started as an international project in 2003. Participating countries are Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine and Turkey. Meanwhile, with the help of European funds, SESAME has been substantially expanded. It will take up operation as a modern synchrotron radiation source in 2014/15.

Starting signal for Ioffe Röntgen Institute

On 23 May in Moscow, DESY directors Helmut Dosch and Edgar Weckert and the director of the Kurchatov Institute, Mihail Kovalchuk, signed a letter of intent for the foundation of the Ioffe Röntgen Institute. The planned institution will intensify the cooperation between German and Russian scientists.

Helmut Dosch and Mihail Kovalchuk (Kurchatov institute)

The new Ioffe Röntgen Institute (IRI) will be the common umbrella for all bilateral projects and initiatives regarding large-scale photon, neutron and ion sources, thus allowing an even closer collaboration between both countries in these strategically important research fields. DESY and the Kurchatov Institute will coordinate and support all content-related and organizational activities. Offices are planned at both locations. The most important partners will be other Helmholtz institutes, but also other universities and research institutes. The IRI is due to be inaugurated in the first half of 2012.

The name of the institute goes back to the discoverer of X-ray radiation Wilhelm Conrad Röntgen and the Russian physicist Abram Fjodorowitsch Ioffe, who was a PhD student of Röntgen and is considered the father of Russian semiconductor physics.

Cooperation agreement with Saha Institute of Nuclear Physics

At the end of May, German Chancellor Angela Merkel travelled to India with a delegation including DESY directors Helmut Dosch and Christian Scherf. In Delhi, they signed a cooperation agreement between DESY and the Saha Institute of Nuclear Physics (SINP, Kolkata), represented by its director Milan Sanyal. The agreement manifests the intention of the German and Indian partners to intensify their cooperation in the field of large-scale research infrastructures.

From left: Helmut Dosch, German Chancellor Angela Merkel, Indian Prime Minister Manmohan Singh and SINP director Milan Sanyal

DESY's light sources PETRA III and FLASH are extremely attractive for India's well-developed and highly qualified science community. India is planning to build its own third-generation synchrotron radiation source and is very much interested in training young scientists at the DESY facilities.

In 2009 already, the scientific adviser to the Indian government, C.N.R. Rao, signaled the country's intention to carry out nanotechnology and materials research at PETRA III, including participation in a future PETRA III beamline. The current agreement with SINP provides the legal framework for a variety of projects and initiatives, represented and coordinated for India by SINP. As a first concrete activity, SINP will contribute 14 million euro to the construction and operation of a beamline in one of the PETRA III extensions. DESY and SINP are also discussing possibilities for additional cooperation in the field of accelerators and instrumentation.

June

New Accelerator Research and Development programme

On 1 June, the Senate of the Helmholtz Association approved the Accelerator Research and Development (ARD) initiative, a new programme in the portfolio of the research area "Structure of Matter". The initiative was launched by the six Helmholtz centres DESY, FZJ, GSI, HZB, HZDR and KIT in 2010, with DESY acting as the coordinating laboratory. With the approval, a total funding of about 17 million euro over the period 2011–2014 will be provided to the six centres involved in accelerator R&D. From 2015, the ARD programme will be continued as part of the third round of programme-oriented funding (PoF-III). Members of the ARD team held their start-up meeting at DESY just a few days after the approval.

First meeting of the ARD team from six Helmholtz centres on 7 June at DESY

The ARD programme is structured into four topics: superconducting RF technology; concepts and technology for hadron accelerators; picosecond and femtosecond electron and photon beams; and novel acceleration concepts. DESY participates in the topics 1, 3 and 4. The implementation of ARD as an independent new programme underlines the importance of accelerators as enabling technology for many areas in fundamental science and applications, improves the visibility of the field and further increases its attraction to young people. The ARD initiative strengthens the networking between the centres and with universities and serves as a platform for international cooperations.

Royal visit to DESY

During her two-day stay in Hamburg, Princess Maha Chakri Sirindhorn from Thailand took the opportunity to visit DESY, where she was welcomed by Helmut Dosch, chairman of the DESY Board of Directors. DESY research director Edgar Weckert then took Her Royal Highness on a tour of the new PETRA III experimental stations.

Helmut Dosch offers a model of a superconducting cavity to Princess Maha Chakri Sirindhorn

Princess Sirindhorn is very interested in science and technology, and DESY is well known to her. On her last visit to the research centre nine years ago, an agreement was signed on Thailand's participation in the DESY summer students programme. Since then, 15 Thai students – hand-picked by the princess – took part in the two-month training programme, with excellent results. During the June visit of the princess, the possibilities to extend the programme were also discussed. Thai scientists already participate in DESY projects such as the PITZ photoinjector test facility in Zeuthen.

Maha Chakri Sirindhorn, crown princess of Thailand, is very popular among the Thai people. She has an extensive expertise, particularly in the field of new technologies; she speaks English, French and Chinese fluently and currently learns German and Latin. She is the third child of King Bhumibol Adulyadej and Queen Sirikit.

July

First continuous-wave and long-pulse operation of European-XFEL-type cryomodule

Continuous-wave (CW) and long-pulse (LP) operation modes of the linear accelerator are attractive future options to enhance the experimental potential of the European XFEL. On 7 July, a two-week test was finished in which a European-XFEL-type cryomodule was operated for the first time in both CW and LP modes with accelerating gradients up to 5.5 MV/m and 11.5 MV/m, respectively.

At first go already, the stability of the accelerating gradients of all eight cavities exceeded 10^{-3} rms for both operation with 300-ms-long pulses and CW operation. This test showed that the stability could be further improved by the implementation of dedicated control electronics (low-level radio frequency, LLRF), which were due to be ready for the second run in fall 2011.

The new operation modes require new RF amplifiers to replace the high-power klystrons, which are similar to the ones used at present in FLASH and deliver RF power in 1.5-ms-short pulses only. For the test, a prototype of the 80-kW inductive output tube (IOT) designed and built by CPI Company in the USA was used. The IOT was funded through the first EuroFEL programme, in which DESY participated in 2005–2007. DESY had proposed the R&D programme devoted to the LP operation mode in 2005.

This encouraging result is a first step towards more flexibility in the operation of the European XFEL and FLASH and possibly also of other free-electron laser facilities with driving linacs based on the TESLA technology. The experiments at the Cryo Module Test Bench (CMTB) were proposed at the first DESY accelerator ideas market in 2010. The development of superconducting RF technology in CW mode is part of the recently approved and funded Accelerator Research and Development (ARD) programme of the Helmholtz Association. This first experiment was prepared and conducted within relatively short time at DESY in cooperation with the Technical University Łódź, the Warsaw University of Technology and the Soltan Institute for Nuclear Studies in Świerk.

August

Boring of European XFEL accelerator tunnel completed

On 27 July, the European XFEL tunnel boring machine TULA ("tunnel for laser") slowly drilled through the wall of its reception shaft on the DESY-Bahrenfeld site. With a landing precision of one millimetre, TULA arrived in its travel-out panel on the western wall of the European XFEL injector building.

The cutterhead of TULA

The construction of the 2010-m-long accelerator tunnel was not yet finished, however. Six reinforced concrete rings – the last of which connects the tunnel with the hall – were still missing. While TULA inched its way onto the large steel jack (the “shield cradle”) that was installed in the hall especially for this purpose, the tunnel builders assembled the last concrete rings. On 6 August, the boring of the tunnel tube for the superconducting accelerator of the European XFEL was finally completed.

After more than 400 days of service for European XFEL, TULA had completed its job. In the following days, it was dismantled inside the injector building and transported in parts through the narrow shaft back to the surface, to be returned to the manufacturer by ship. The dismantling of the infrastructure needed for the machine (catwalk, supply pipes, cables and the tracks of the tunnel railway) took place in parallel. The tunnel construction also included fitting the tunnel tube with a stable, flat floor, which was due to be completed in January 2012. With the help of a special vehicle, the substructure was constructed from precast concrete elements weighing six tonnes each. The floor panels were then laid on top of this substructure.

September

Construction start for FLASH II

For years, FLASH has been generating X-ray laser light for an ever-increasing user community. In September, construction started for the next expansion stage, FLASH II, with the aim of serving more users and at the same time implementing the most recent developments of free-electron laser technology.

First digging at the FLASH accelerator tunnel

The extension of FLASH is one of the strategic investments of the Helmholtz Association, which provides nearly 30 million euro for the project. Commissioning of FLASH II is planned for 2013. In a new experimental hall next to the existing FLASH hall, five measuring stations will gradually be made available for the use of the highly demanded FEL radiation. For this purpose, the existing superconducting linear accelerator is being expanded with a second tunnel section including a second line of undulators, in which up to 8000 electron bunches per second will be made to emit laser radiation with wavelengths down to 4 nm. This radiation will then be distributed to individually equipped beamlines. FLASH II will be equipped with variable-field-strength undulators and deliver light pulses with durations between 30 and 500 fs.

In the first construction phase, the connection to the existing FLASH accelerator tunnel is being built, which makes it necessary to remove the earth wall from the tunnel. The next step will be the construction of the electron beam dump.

October

Christian Stegmann new head of DESY, Zeuthen Site

On 1 October, Christian Stegmann assumed office as new head of DESY, Zeuthen Site, and representative of the Zeuthen institute in the DESY Board of Directors. He was simultaneously appointed professor at the University of Potsdam.

Professor Christian Stegmann

Christian Stegmann, born in 1965, was professor at the University of Erlangen-Nürnberg. The astroparticle physicist works at the H.E.S.S. (High Energy Spectroscopic System) experiment, a system of Cherenkov detectors in Namibia that allows scientists to explore cosmic showers of ultrahigh-energy gamma particles.

Stegmann has been associated with DESY for a long time. At the end of his diploma physics studies at the University of Bonn, he graduated at the ZEUS experiment in Hamburg. In 1995, after his doctorate at the University of Freiburg, Stegmann came to DESY, Zeuthen Site, and worked at the HERA-B detector for five years. After that, he focused on earthbound astroparticle physics.

Stegmann takes over the management of the Zeuthen institute from Hans-Jürgen Grabosch, who was the provisional manager after the retirement of long-term Zeuthen head Ulrich Gensch.

Federal Cross of Merit for Ulrich Gensch

On 12 October, Ulrich Gensch was awarded the Federal Cross of Merit First Class of the Federal Republic of Germany. Ulrich Gensch, who retired on 1 June, was the representative of the DESY Board of Directors in Zeuthen for 13 years. Before this time, he headed one of the departments at DESY, Hamburg Site, for three years. He received the Federal Cross of Merit for his outstanding contributions to the development of Germany as a location for science and industry.

Federal Research Minister Annette Schavan honours Ulrich Gensch. (Photo: BMBF)

As the awarding statement reads: “With effective concepts, a judicious political approach and strong personal dedication, as an initiator and competent actor, you supported the integration of the Institute for High-Energy Physics (IfH) of the GDR Academy of Sciences into DESY.” With this, Gensch gave the institute a clear and promising perspective and, at the same time, contributed visibly and effectively to strengthening DESY’s potential as a world-leading user laboratory and renowned training centre.

Start of European project CRISP

Within the framework of the European project CRISP, 16 European physics research centres join forces for the first time to collaborate on central technical issues for their future research infrastructures and profit from each other's experience. With its work on X-ray free-electron lasers, DESY has taken over the leadership of the accelerator field. In October, the Cluster of Research Infrastructures for Synergies in Physics (CRISP) was launched at the Czech embassy in Paris.

In the coming three years, CRISP will explore four core fields: accelerators; instruments and experiments; detectors and data acquisition; IT and data management. The EU project, which receives a funding of 12 million euro, regards accelerator advancement as a prerequisite to providing future research projects with state-of-the-art X-ray, ion and neutron sources, and to successfully coping with future challenges in nuclear and high-energy physics.

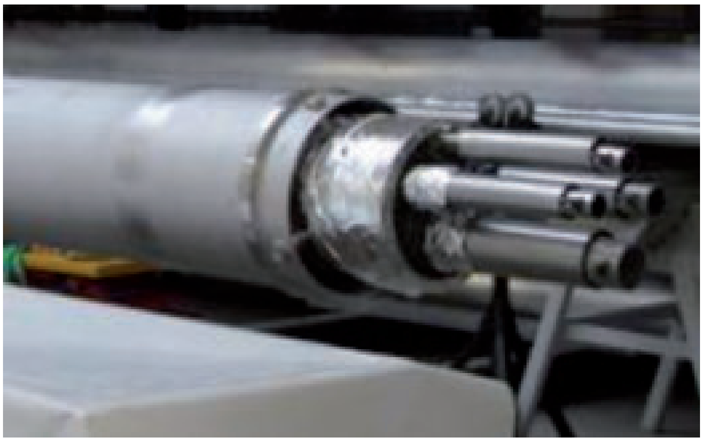
Superconducting accelerator modules as they are used at FLASH and the European XFEL have set the quasi-standard for future large accelerator projects. The know-how gathered at projects such as the free-electron lasers in Hamburg is to be developed into an industrial standard for the commercial production of such structures. DESY will also make important contributions to the other three fields. The research opportunities provided by free-electron lasers can only be exploited using new measuring instruments with resolutions in the femtosecond range. The standards required for the detectors and the data acquisition are correspondingly high. For the detectors, a carbon dioxide cooling is to be developed within the framework of CRISP. The huge amount of data poses completely new challenges for IT. Here, CRISP will develop a common solution for high-speed recording and storage, and test data processing concepts like distributed computing.

CRISP aims at creating synergies between eleven major research infrastructures that are planned or already under construction. These projects are part of the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) and include European XFEL, ESS, ELI, EuroFEL, ILC-HiGrade and SKA, as well as upgrades of ESRFUP, FAIR, ILL, SLHC and SPIRAL. EU research funding becomes an increasingly important tool to intensify the cooperation of scientists in Europe. Besides the scientific goals, networking of partner institutes and joint and coordinated strategic handling of research themes is of great interest to DESY – with up to 50 partners working together in some cases.

CRISP workshop in Paris

First helium transfer line modules arrive from Poland

The accelerator of the European XFEL will be operated at minus 271°C. Before assembly, the main accelerator elements have to be tested at operating temperature. For these tests, tonnes of liquid helium will flow between the new DESY Accelerator Module Test Facility (AMTF) and the cryogenic plant. The first modules of the helium transfer line arrived at DESY from Wrocław, Poland, in October. Along with the test cryostats and the actual testing, which is due to start in 2012, they belong to Poland's in-kind contribution to the European XFEL.



The transport of cold helium is anything but trivial. The transfer line must operate reliably in all weather conditions without the helium warming up. This is ensured by a complex design that includes four process pipes running in the core of an external pipe with a diameter of around 40 cm, one each for the transport and re-transport of cold helium at 4 K and 40 K.

The construction of the transfer pipe is the charge of the Wroclaw University of Technology. The modules are produced by the firm KrioSystems and transported to Hamburg in 12-m units. The first 60 m have already arrived. Assembly started in November. In April 2012, the two test cryostats are due to arrive from Wroclaw. They will be 3.8 m high, with a diameter of 1 m, and filled with 2 m^3 of liquid helium each. The cryostats will be embedded in the floor of the AMTF hall. In this cold bath, four niobium cavities will be tested simultaneously before being dispatched to CEA in Saclay for mounting. Here, eight cavities at a time will be assembled into an accelerator module, which will then be returned to Hamburg. Before it is finally installed in the European XFEL accelerator tunnel, each accelerator module will be tested again in the AMTF hall. The cavity and module tests are carried out under the responsibility of a team from the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences of Cracow.

13 600 visitors on Open Day and Science Night

Until midnight on 29 October, 13 621 visitors flocked to the DESY campus in Hamburg Bahrenfeld for the DESY Open Day and Science Night – meaning that two out of three participants of the 4th Hamburg Science Night visited DESY.

Hamburg's Science Senator Dorothee Stapelfeldt and Helmut Dosch visit an experimental station at PETRA III.

More than 60 attractions provided insight into DESY activities. Highlights included the tunnel of Germany's largest accelerator, HERA, the FLASH free-electron laser and the huge PETRA III experimental hall. The first visitors came already before the official opening at 12:00, the last ones arrived at 23:45. People were not only interested in top-level research, but also in the activities of the DESY workshops and the school lab. Visitors had the opportunity to monitor a huge hall crane, saw tree grates, get their Bobby Car driving distance measured with a laser, or experiment with a chocolate marshmallow in an evacuated jar. About 850 helpers explained DESY activities to the guests, distributed 21 600 gummi bear bags, 4400 balloons and 3000 apples with a DESY logo on it. More than 1000 budding scientists took part in a rally through the FLASH hall, winning a special-edition PIXI book about DESY.

More than 20 000 people participated in the 4th Hamburg Science Night. DESY was one of 45 science facilities that opened their doors to the public. “I am glad that so many universities and research facilities took part in this event,” said Hamburg's Science Senator Dorothee Stapelfeldt, who also visited DESY. “The response to this wide range of attractions shows the great interest of citizens in science and research. I am especially pleased about the large number of children and young people who made use of this opportunity together with their parents.”

November

Award for outstanding PhD theses

The annual PhD thesis award of the Association of the Friends and Sponsors of DESY (VFFD) was shared by Dr. Martin Beye and Dr. Roman Kogler. Martin Beye earned his doctoral degree at FLASH, Roman Kogler in the H1 collaboration at HERA.

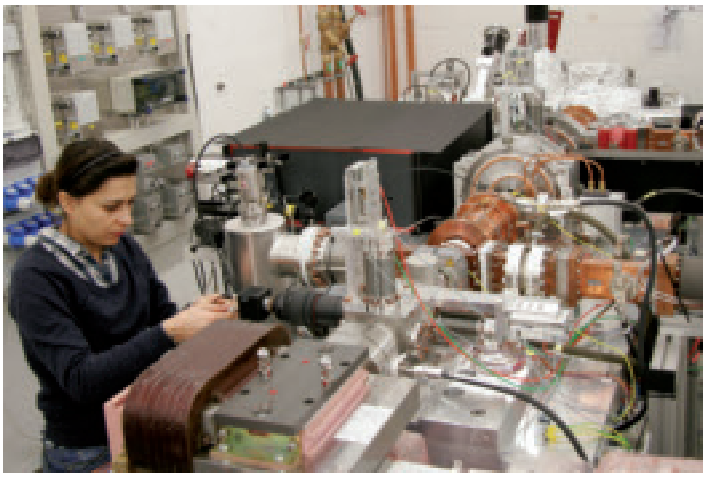
From left: Martin Beye, VFFD Chairman Friedrich-Wilhelm Büßer, Helmut Dosch and Roman Kogler

For his PhD thesis, Martin Beye worked on a series of internationally much-noticed experiments at FLASH, gaining completely new insights into the dynamics of matter. Among other things, he experimentally observed a new liquid phase of silicon for the first time. This finding has far-reaching significance for our understanding of the properties of liquids, e.g. the well-known density anomaly of water which entails that at 4°C, water has a higher density than solid ice.

In his PhD thesis, Roman Kogler presented precision measurements of 2-jet und 3-jet events at H1. The particle bunches (jets) emerging from particle collisions provide information about the dynamics of the quarks and gluons involved in the collisions. Kogler developed a new and efficient method to evaluate these particle jets, which clearly improves the precision of jet measurements compared to previous analyses.

First electrons light up at REGAE

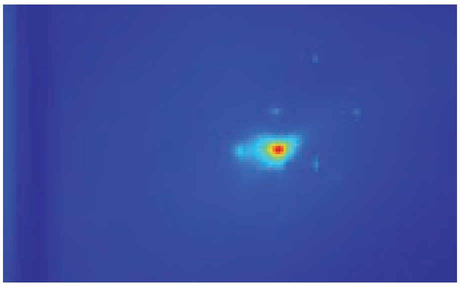
One of DESY's smallest accelerators reached an important milestone: the Relativistic Electron Gun for Atomic Exploration (REGAE) accelerated its first electrons, thereby officially starting operation.



Shima Bayesteh at the REGAE facility in Building 23

REGAE is a joint project of the CFEL partners Max Planck Society, University of Hamburg and DESY. The approximately 10-m-long facility will generate highly coherent ultrashort electron pulses to carry out time-resolved structural investigations of crystallized materials and possibly push the boundaries to in situ studies of liquids, surface and solution phase chemistry on the nanoscale. REGAE will produce electron bunches with only about 10 fs length, thus allowing experiments with an extremely high time resolution. REGAE's electron source is similar to the one in FLASH, but working with a radio frequency of 3 GHz. The electron bunches, which comprise a thousand times less electrons than in FLASH, are accelerated to 5 MeV and packed tightly together using a buncher cavity. The optical laser that triggers the electron bunch in the source can be used simultaneously to excite the sample, allowing pump-probe experiments.

After commissioning of the 2-million-euro facility, the REGAE group will put the diagnosis systems into operation, optimize the synchronization software and complete the vacuum system. First experiments could be carried out in January 2012. As a further perspective, it is planned to use REGAE's femtosecond beam to explore electron injection into a plasma wave excited by a high-power laser and test ultrahigh-gradient acceleration.



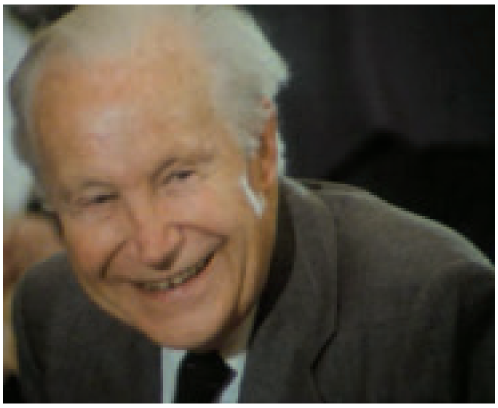
First electrons show up on the REGAE control screen.

December

DESY recalls its founding father

On 6 December, Prof. Willibald Jentschke, the founding father of DESY, would have turned 100 years.

Willibald Jentschke, born in Vienna, was appointed professor at the University of Hamburg in 1955. With his research work in Austria and the USA, he had gained a reputation in nuclear physics, and thus was to establish nuclear physics in Germany again. For his professorship in Hamburg, Jentschke envisioned something that could not be carried out by one university alone: he planned to build a globally competitive accelerator for particle physics. With his great persuasiveness and negotiating skills, he convinced the funding authorities from Hamburg and the German government to grant him the incredible sum of 7.5 million deutschmarks for his project – the root of today's research centre DESY.



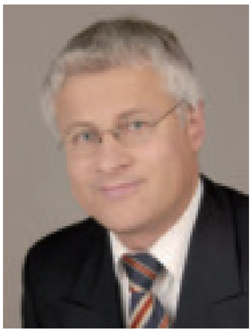
Professor Willibald Jentschke

Jentschke was chairman of the DESY Board of Directors from 1959 to 1970. Afterwards, as director-general of CERN, but also after his retirement and into old age, he was always actively involved in particle physics and very interested in "his" DESY developing into one of the world's leading accelerator laboratories. Willibald Jentschke passed away in 2002, a few months after his 90th birthday. Every year, DESY organizes the Jentschke Lectures in his honour.

Prestigious grant for nanoscience at PETRA III

For his investigations of nanoparticle growth at PETRA III, Prof. Stephan Förster from Bayreuth University was honoured with the highest science award of the European Research Council (ERC). The ERC Advanced Grant is endowed with 2.4 million euro and is presented for particularly promising research projects.

Using the 20-µm X-ray beam available at the microfocus beamline P03 (MiNaXS) at PETRA III, Förster and his team irradiate mixtures of different liquids on chips with microscopic channels. Their aim is to investigate how atoms congregate into small clusters in liquids and how these nanoparticles grow. These findings are not only important for basic research, but also for the development of new materials as well as for energy, information and medical technologies. In future, the resolution is to be increased to 1 µm.


Professor Stephan Förster

Japanese ILC delegation visits European labs

Two Japanese regions are possible candidates for the home of the proposed next-generation particle accelerator, the International Linear Collider (ILC). A delegation from one of the regions, the prefectures Fukuoka and Saga on the Japanese island of Kyushu, visited DESY and CERN to learn more about existing research infrastructures and the labs' experience with management, administration, local communication etc.


The Japanese ILC delegation at DESY

Even though a site for the ILC will not be chosen before first results from CERN's LHC determine the future of particle physics, Japan is a strong contender for hosting the project. The delegation, consisting of four members of the Fukuoka/Saga ILC planning committee, wanted to establish a dialogue with the European labs to exchange ideas and information. At DESY, they heard about DESY regional cooperation, socio-economic impacts, innovation and technology transfer, outreach with local communities and of course DESY and the ILC. They also visited the cavity preparation and testing facilities on campus, including the new Accelerator Module Test Facility (AMTF) for the European XFEL, as well as FLASH and PETRA III.

Perfect layer for the right spin

The next generation of electronics is spintronics, which uses not only the electrical charge of electrons but also their spin. At PETRA III, a group of scientists headed by Martina Müller from Forschungszentrum Jülich explored a promising material for spintronics: europium oxide, which is excellent to produce and read out electron currents with a defined spin in a silicon semiconductor.

Müller's team achieved an important step on the way towards developing semiconductor-based spintronics, e.g. spin transistors. The goal is to find materials that can easily be integrated into current silicon technology. A suitable material would be europium oxide, which is structurally, chemically and electronically compatible with silicon. It is one of the highly traded candidates for spin filters, which allow injecting an electron current with high spin polarization into a semiconductor.

The Jülich scientists grew a 4.5-nm-thin europium oxide nanolayer directly on silicon. The chemical composition of the layer cannot be determined from the outside, as it is protected by a 4-nm-thick aluminium cover. Such a relatively thick structure cannot be penetrated with the energies of electrons used in standard photoelectron spectroscopy. Thanks to the unique brilliance of PETRA III, however, it is possible to produce very fast photoelectrons to gaze deep into the samples, right down to the silicon layer. The analysis showed that Müller's team managed to grow a nearly pure layer of europium oxide directly on silicon, without unwanted admixtures. The silicon too was nearly undisturbed, with practically no silicon oxide – a decisive feature. This sensitive analysis technology made possible by PETRA III has great potential for the future, as multilayers are a growing research field with regard to electronics applications.

Reinhard Brinkmann confirmed in office

In its 14 December session, the DESY Administrative Council appointed Reinhard Brinkmann as director of the accelerator division for another five years. His second term will begin on 1 July 2012.

Reinhard Brinkmann has been director of the accelerator division, the largest of the three research sectors at DESY, since 2007. He started working at DESY in 1984 and was always involved in the development of accelerators at DESY – as HERA machine coordinator, during the conception of the TESLA linear collider, or within the European XFEL project. His second term stands for the advancement of DESY's comprehensive activities in the construction and operation of particle accelerators. Only recently, on Brinkmann's initiative, the Helmholtz Association launched the Accelerator Research and Development (ARD) programme, of which he is the coordinator. The initiative bundles competences and resources to develop accelerator technologies and concepts tailor-made for future challenges in basic research, as well as for applications in medicine, materials science and other areas.

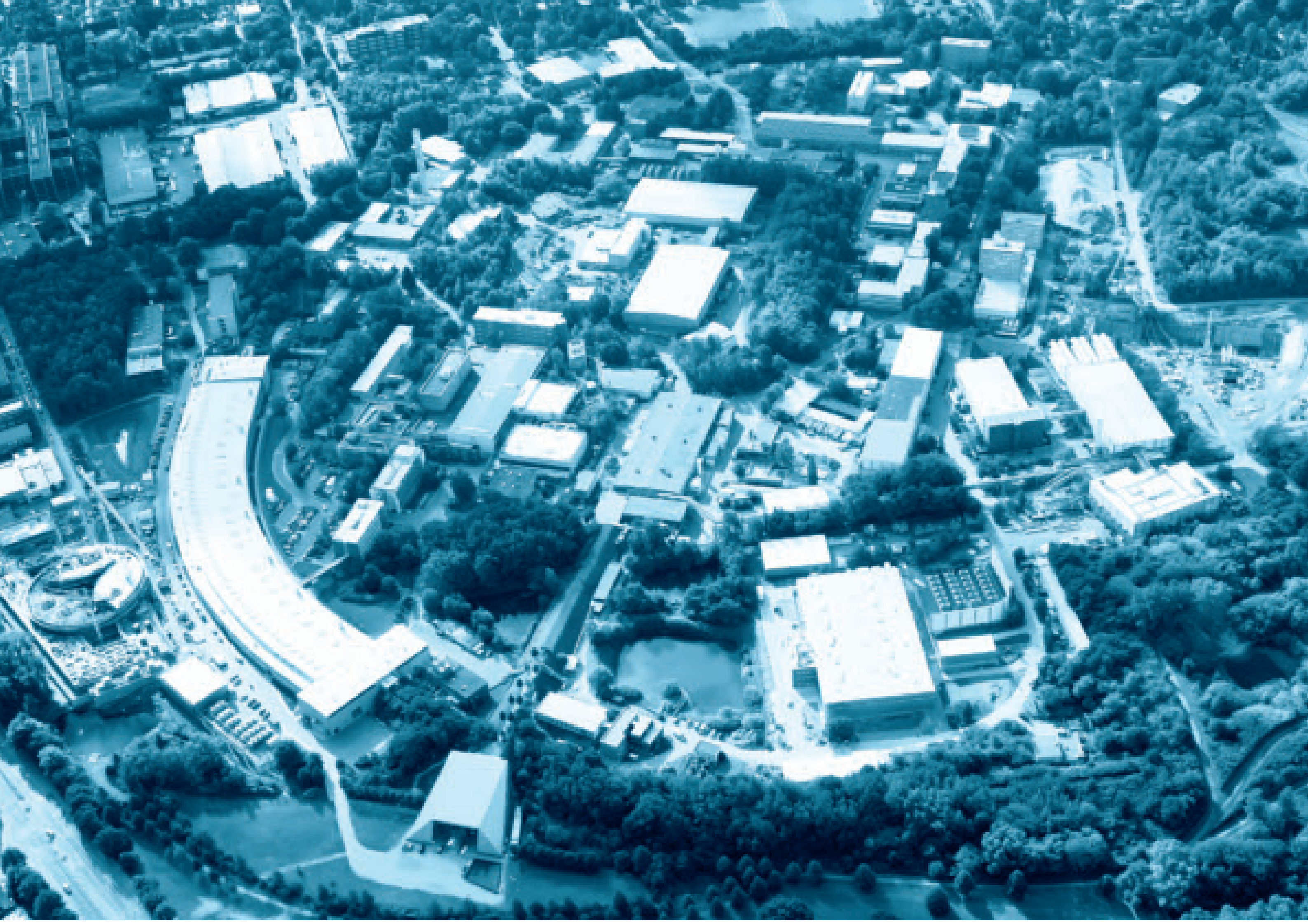
Reinhard Brinkmann

DESY cooperates with Indian research centre

On 21 December, an agreement was signed in the presence of Hamburg's Science Senator Dorothee Stapelfeldt that defines Indian participation in the X-ray sources PETRA III and FLASH.

From left: Helmut Dosch, Hamburg's Science Senator Dorothee Stapelfeldt, C.N.R. Rao, Chairman of the Science Advisory Council to the Indian Prime Minister, and SINP Director Milan Sanyal

DESY and the Saha Institute of Nuclear Physics (SINP, India) thereby concretize a general cooperation agreement that was concluded in May 2011 during the visit of German Chancellor Angela Merkel to India. For five years, more than 3500 hours of measuring time at DESY research facilities will be made available to Indian scientists for joint research projects with DESY. India will also contribute 14 million euro to the construction of the PETRA III extension.



Accelerator operation and construction.

DORIS III.

Combining two worlds of research

In 2011, the DORIS III storage ring ran over 7.5 months in its standard operation mode as a source for high-flux, hard X-ray beams. The new OLYMPUS detector was installed in its final position during a short break in the summer. In the second half of the year, the detector was finalized and the DORIS III operation mode for the nuclear physics runs in 2012 was developed and tested.

Synchrotron radiation run 2011

After the modification of the DORIS III ring for the new OLYMPUS experiment during the winter shutdown 2010/11 and a subsequent period of vacuum conditioning and machine studies, the synchrotron radiation run 2011 started on 28 February. The new OLYMPUS interaction region had been designed with the goal to keep the beam parameters at all beamlines as far as possible unchanged. It was thus possible to restart the photon user operation after a very short beamline commissioning period.

In 2011, DORIS III delivered a total beam time of 4825 hours with an availability of 90.9% and a mean time between failures (MTBF) of 33.7 hours. These disappointing numbers were caused by technical failures. In May, two longer breaks were necessary due to a water leakage in a vacuum chamber and a vacuum leakage in a bellow. During autumn, frequent partial beam losses due to fluctuations in the magnet currents significantly reduced the MTBF. Two weeks of undisturbed beam operation improved the situation at the end of the year.

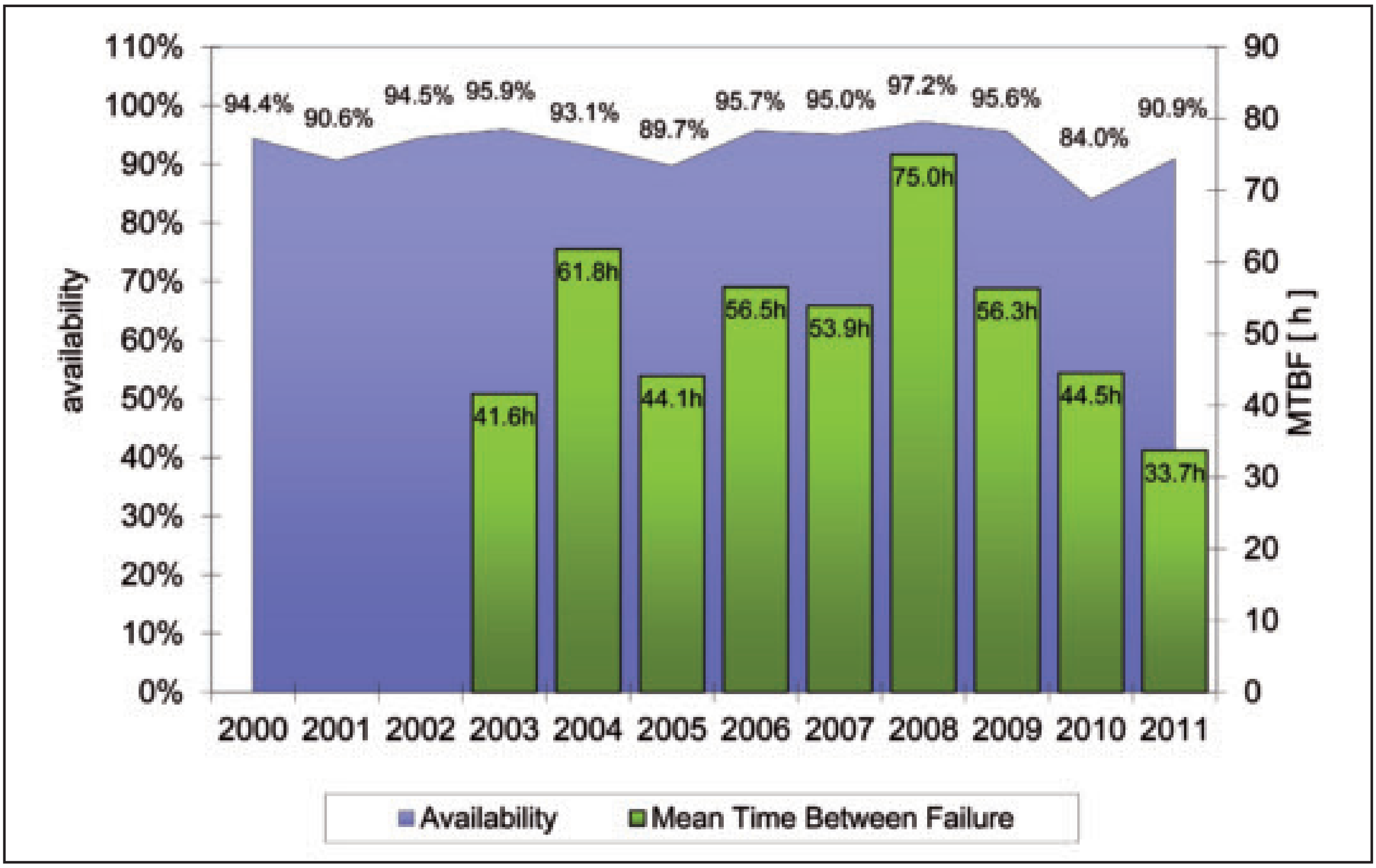


Figure 1

Availability and mean time between failures for the last years of DORIS III operation

Figure 2

The moment of truth when the OLYMPUS detector rolls in towards the DORIS III ring

OLYMPUS at DORIS III

The new DORIS III beam optics and vacuum system, including the OLYMPUS scattering chamber with the gas target system, were tested in February. The two operation modes – running as a synchrotron radiation source at 4.5 GeV beam energy as well as supplying a 2.0-GeV beam for nuclear physics – were successfully established. The time needed for switching between the two modes could be minimized to about half an hour. For the first time, DORIS III is now able to switch the polarity of the stored particles without hardware modifications together with all pre-accelerators. DORIS III was set up with electrons and positrons with no obvious differences in the beam quality. After these studies the scattering chamber was removed, because the observed heating of the inner target cell due to wake fields exceeded the acceptable limits.

During four weeks in July, the interaction region was opened again and the completed OLYMPUS detector installed, including the significantly improved scattering chamber. After comprehensive beam dynamics studies and tests of the detector, the second period of synchrotron radiation runs started on 15 August. On several days during the second half of the year, the OLYMPUS detector components, electronics and software were tested and debugged to prepare the first run in February 2012.

To minimize the signal background from lost particles, four stations with two collimators each were refurbished. Two of these stations are placed just in front of the detector and two are in position further upstream the beamline. By optimizing the beam conditions and the collimator settings, the particle-induced background could be reduced by about one order of magnitude. When switching the polarity from positrons to electrons the overall beam conditions were practically unchanged, which is essential since the direct comparison of these particle types is crucial for the experiment.

Contact: Frank Brinker, frank.brinker@desy.de

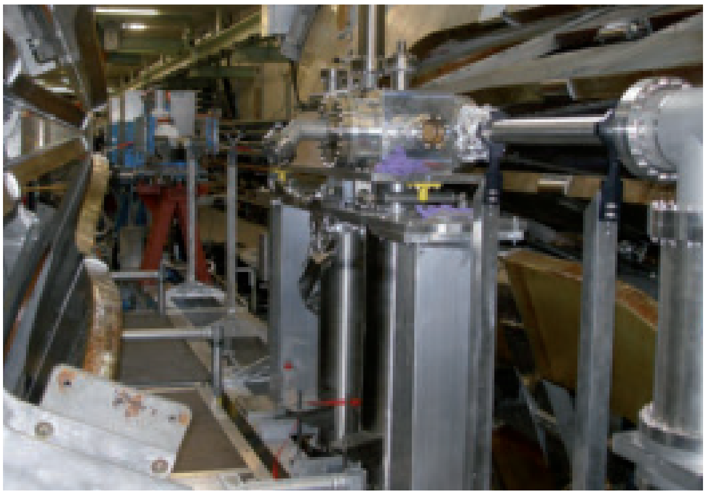


Figure 3

View through the freshly installed detector into the tunnel. The detector frame with the magnet coils for a toroidal field is still open. The scattering chamber in the centre is waiting for vacuum connections.

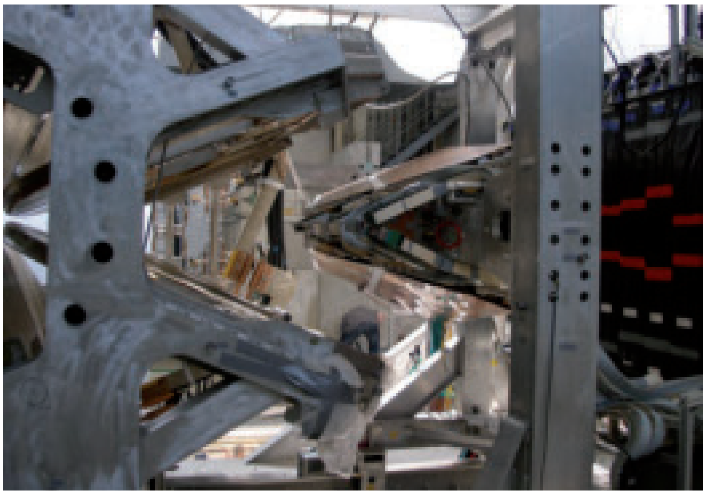


Figure 4

The main detector on the left is closed and the wire chamber on the right is prepared to move into the gap between the coils.

PETRA III.

Operation and future extension

The year 2011 was the first to be fully devoted to user operation, and PETRA III was operated for more than 4750 hours for users. In addition, studies and experiments were carried out to gain a deeper insight into the behaviour of the accelerator, which is important for the planned extension of PETRA III and to improve the performance of the machine. The accelerator design for the extension of PETRA III was refined and worked out in more detail.

User operation

After a short winter shutdown, operation of PETRA III resumed in February 2011. The first two weeks were required to set up the accelerator and carry out studies to improve operation and address specific problems that are relevant for the extension of PETRA III in 2013. The user run started at the beginning of March and ended on 21 December. In July and August, the user run was interrupted by a five-week-long shutdown required to work on and test the interlock systems. During the rest of the year, there were a few service weeks, and user operation normally paused on Wednesdays for about 24 hours for maintenance and machine development. The beam time distribution in 2011 is shown in Fig. 1.

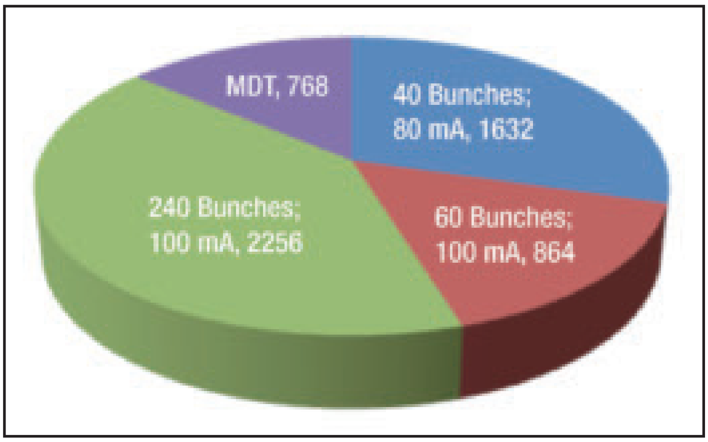


Figure 1

The diagram displays the distribution of the beam time (5520 h) in 2011. Shown are the number of bunches, the total current and the time in hours. For users, PETRA III was operated either in a so-called timing mode with 40 or 60 bunches, respectively, or with 240 bunches. About 770 h were devoted to studying and improving accelerator operation (machine development time, MDT).

The machine basically ran with design parameters, but studies were carried out to verify some of the parameters and improve operation. In 2010, there were some doubts whether the vertical emittance was close to the design value of 10 pm rad. In the first half of 2011, the bunch length measurement was replaced by a new emittance measurement technique to determine the vertical emittance. With the help of this new measurement, it could be proved that the vertical emittance is actually as small as 10 pm rad. Studies of betatron coupling, emittance measurement and control are still ongoing.

According to Fig. 1, the current during user operation is usually 100 mA, with the exception of the 40-bunch mode. The total current in this mode is limited by a technical deficiency of the RF shielding in the bellows in front and behind the undulator chambers. The optimistic assumption that this problem can be alleviated by increasing the spring constant of these RF shields did not turn out to be true. To get rid of the problem, all shields have to be replaced. This procedure will be accomplished in 2013. Attempts to increase the number of bunches beyond 240 bunches failed because of a vertical blow-up of the beam, probably due to electron cloud effects. Studies are still ongoing to verify whether this effect will fundamentally limit the number of bunches.

The reproducibility of the orbit position at the different insertion devices from run to run or after beam loss has been improved. The reproducibility and the long- and short-term stability are now within the specifications of 10 µm horizontally and 0.5 µm vertically. The complete procedure to establish the correct orbit position at the insertion devices has been significantly improved. It is now robust and reliable.

During the winter shutdown 2010–2011, it was observed that some of the undulator poles show traces of corrosion. The corrosion of the poles is due to an interaction of synchrotron radiation coming from the upstream dipoles and the humidity and air in the accelerator tunnel in the new octant. To avoid further corrosion, the air-conditioning system of the accelerator tunnel will be modified so that humidity is drastically reduced. Radiation damage is also a problem in the two damping-wiggler sections. The coil insulation of quadrupoles close to synchrotron radiation absorbers shows colour changes, and some cables in the vicinity of the 4.5-m-long absorbers were damaged. Meanwhile, first ideas to build radiation shields have been put forward. Installation will probably take place in 2012 or 2013.

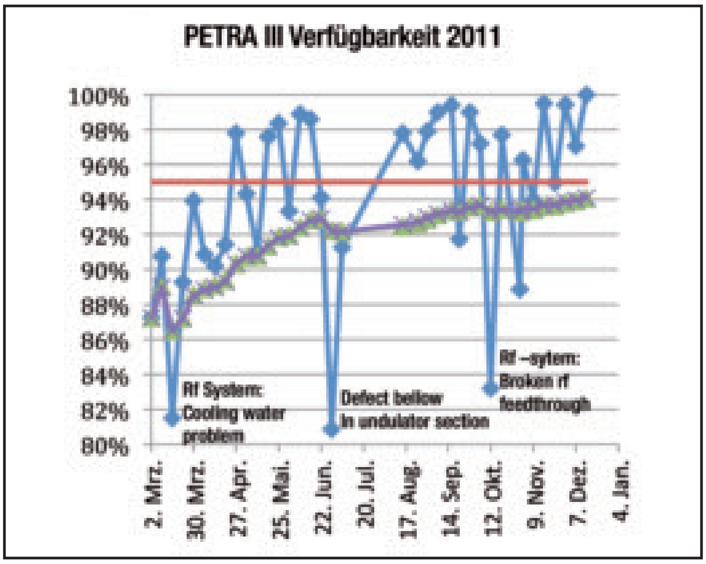


Figure 2

Availability in 2011. The blue curve shows the weekly average, the grey curve the yearly average. The solid red line indicates the target availability of 95%.

High reliability and availability is one of the key requirements of the users. At the end of 2010, the availability was close to or even higher than the necessary 95%. Unfortunately, for different reasons, the availability at the beginning of the run in 2011 was sometimes well below the target of 95%. The water cooling of the RF systems suffered from either malfunctioning flow detectors or from obstruction of water flow by dirt.

Several beam losses were caused by a problem with the coupled bunch feedback system and it took quite some time to figure out the reason. As a consequence, the software of the system will be extended to monitor the operation of the system more closely.

Two major events caused an interruption of machine operation for a few days. One was due to a damaged RF shield that had to be replaced and the other by an inspection window of one of the RF cavities. Figure 2 shows the evolution of the availability in 2011. Although the target of 95% was just missed, on average the availability at the end of the run was very good. In addition, a new record was established: the machine was operated in top-up mode for more than 10 days without any failure (Fig. 3).

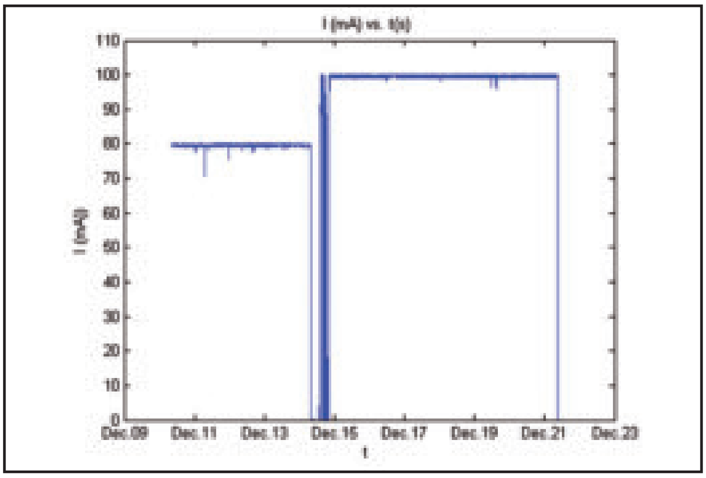


Figure 3

New record: 10 days of top-up operation without failure. The interruption in between is due to a maintenance day.

PETRA III extension

The preparation and design work for the PETRA III extension continued in 2011.To accommodate 10 more beamlines, intensive constructional work will be necessary, and the magnetic lattice of the machine has to be modified in the north and east sections.

During the startup of the accelerator in February, a few accelerator experiments were carried out to investigate the consequences of these modifications. It could be shown that the removal of sextupoles from the machine, which is necessary for the extension, will cause only a slight reduction of dynamic aperture and momentum acceptance in agreement with tracking results. This reduction is acceptable and will not harm the operation of PETRA III after the extension. In addition, we tried to determine the single-bunch current limit. It could be shown that up to 5 mA can be stored in a single bunch, which is twice as much as required for the 40-bunch mode. Since the increase in impedance due to the installation of additional small-gap chambers should be smaller than 100%, the single-bunch current limitation will probably be smaller, but still high enough to run with 100 mA and 40 bunches.

Concerning the design of the accelerator, the lattice changes were fixed and most of the components specified. All the magnets and part of the power supply electronics have already been ordered. The design of the vacuum components is almost finished. Details of the new hall as well as changes of the cabling, water cooling and infrastructure are still under consideration.

It is mandatory that the temperature stability close to the insertion devices in the two remodelled sections be similar to what has been achieved in the new octant. Measurements done in 2011 showed that the present temperature stability is not sufficient. To achieve the required stability, the existing air-cooling systems must be substantially modified or even new systems built, for example in the north. To check that these measures are sufficient, the system in the east will be modified in 2012, and tests will be pursued in summer 2012.

In view of the tight schedule, the time line for the modification was changed. Civil construction will start in March 2013. The modification of the accelerator will be carried out in parallel. According to the present plan, the modifications will be completed by the end of August 2013, followed by a two-to-three-month commissioning period. The first “friendly users” are expected in November, and user operation should resume in 2014.

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FLASH.

Third user period successfully finished before FLASH II construction started

The year 2011 was dedicated to concluding the third user period and starting the construction work for a second undulator beamline, FLASH II. The successful third period started in September 2010 with one year of beam time for user experiments, preparation of beam and beamlines for users, studies to improve the performance of FLASH and general accelerator studies, mainly for the European XFEL and ILC. Compared to the second user period the uptime of the accelerator was improved from 93.1% to 94.4%, reflecting the continuous effort in improving the reliability. The construction of infrastructure for FLASH II started on 19 September 2011. The phase 1 construction work was finished on time, so that FLASH operation will restart on 2 January 2012.

Third user period Sept. 2010 – Sept. 2011

Out of 8834 hours of beam time delivered from September 2010 to September 2011, 56% (4955 h) were dedicated to user experiments. Out of 75 proposals, 29 had been approved by the FLASH project review panel in December 2009. As for the previous periods, the FLASH beam time allocation committee also reserved time for machine studies (37%), maintenance (3%) and a two-week shutdown (4%). Most of the machine study time was devoted to improving the free-electron laser (FEL) performance and to setting up and advancing photon beamlines and diagnostics. Part of the study time (about 15%) was reserved for general accelerator physics studies and developments related to future projects, in particular the European XFEL and the International Linear Collider (ILC).

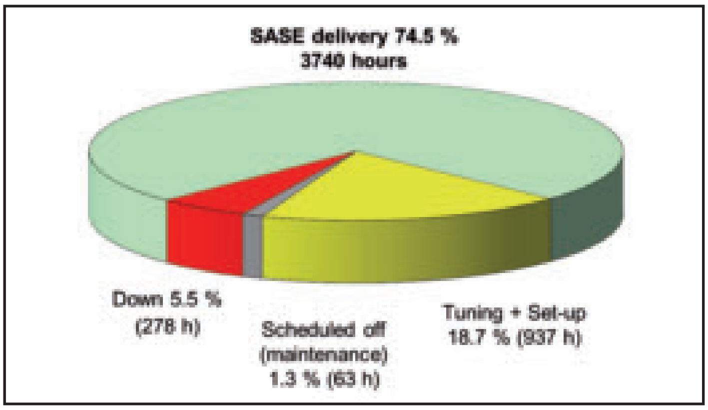

Figure 1

FEL beam or SASE delivery during the third user period from September 2010 to September 2011.

In total, 3740 hours of FEL radiation were delivered to users (Fig. 1). This corresponds to 75% of the dedicated overall user run time. Due to the vast range of requested parameters, such as wavelength, pulse length and pulse pattern, many of them changing from day to day, 19% of the time during the user runs was required for setup and tuning of the machine. However, beam time lost due to down time and tuning time could mostly be compensated by contingency shifts, with the result that 97% of the time originally scheduled for experiments could be realized.

Thanks to the new and improved RF stations installed in 2010 and the continuous effort of the highly skilled DESY staff, the down time of FLASH – with one exception – could be kept at the 4% level, a substantial improvement compared to the second user period, where the downtime was 7%. Unfortunately, a single event in September 2011, a failure of the RF window of the RF gun, forced us to stop the user run prematurely on 5 September. With this event, the down time increased to 5.5%.

During the third user period, more than 30 different wavelengths between 4.7 nm and 45 nm were provided for experiments. Interest was equally divided into one third for short-wavelength operation below 10 nm, one third near 13.5 nm and one third for long-wavelength operation above 20 nm. The delivered bunch train patterns were just as varied, with nearly 50% of

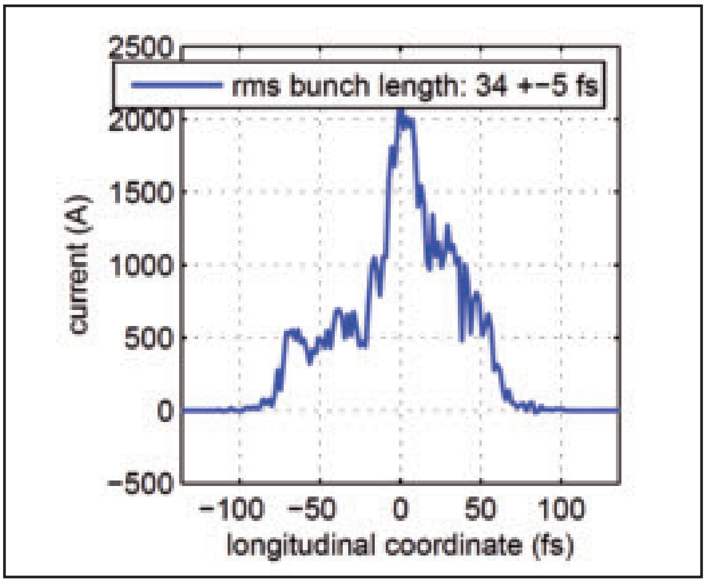

Figure 2

Longitudinal shape of an electron bunch measured with the deflecting cavity LOLA

Figure 4

Construction work along the FLASH tunnel for the new FLASH II undulator beamline

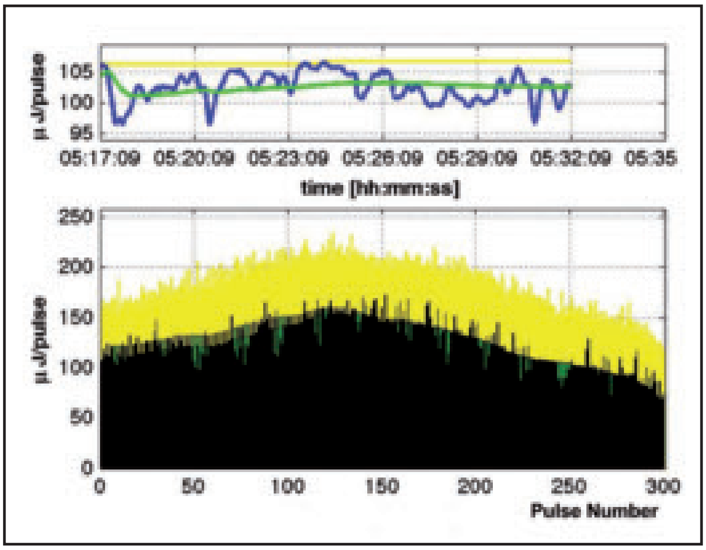

Figure 3

FEL pulse train of 300 pulses with 1 MHz repetition rate at a wavelength of 6.9 nm. The average power of the FEL radiation reaches 300 mW, a new record for FLASH.

single-bunch operation and slightly above 50% of multi-bunch operation with different bunch-to-bunch spacing, all at a bunch train repetition rate of 10 Hz.

With regard to the pulse duration, about one fourth of the experiments required very short pulses below 50 fs. Online techniques to determine the pulse length on a shot-to-shot basis thus take on a strong new focus in the machine and photon diagnostics programme.

Figure 2 shows an example of a longitudinal profile of the electron bunch measured with the transverse deflecting cavity LOLA. The measured rms bunch length is 34 fs. From spectral measurements, the corresponding photon pulse length was estimated to 15 to 25 fs rms.

With the continuous improvement of the low-level RF system stabilizing the amplitude and phase of the accelerating RF, a new record was achieved at FLASH: At 6.9 nm and in a multi-bunch operation of 300 bunches at 1 MHz spacing, an average power exceeding 300 mW was reached (Fig. 3). A similar performance was also obtained at 4.7 nm. Unfortunately, the length of the pulse train was limited by the unusual unsatisfying performance of the RF window of the RF gun.

First experiment in the water window

Early in the third user period, in September 2010, the electron beam energy was successfully increased to 1.25 GeV and lasing in the water window at a wavelength of 4.12 nm in the fundamental was achieved. In the original FLASH design, the majority of beamlines were designed for the 6–80 nm range and use carbon-coated silicon mirrors. Thus, they generally do not transport radiation in the water window between the oxygen *K*(1s) absorption edge (λ = 2.3 nm or 543 eV) and the carbon *K* edge (λ = 4.37 nm or 284 eV) that well. At beamline BL2 in the unfocused branch, the mirrors have nickel as a second coating and a first proof-of-principle in-house experiment could hence be performed at 4.3 nm. It showed that short-wavelength radiation can be transported to the end station at BL2 with a good transmission of 45%. Following this success, an upgrade of the focused branch of beamline BL2 with a nickel-coated ellipsoidal mirror is planned for the next shutdown in early 2013.

FLASH II – a new undulator beamline

Major changes are again in store for FLASH in the next few years. The civil construction for the second undulator beamline – FLASH II – has started (Fig. 4). It required a 3.5-month shutdown of FLASH operation starting on 19 September 2011. Operation will resume on 2 January 2012. In parallel, FLASH II work can press ahead without major disruption of FLASH and PETRA III operation during 2012. A second FLASH shutdown is scheduled for early 2013, when the existing FLASH accelerator will be connected to the new FLASH II undulator beamline. The goal is to complete the FLASH II tunnel and install its major components until spring 2013.

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Rapid progress of the FLASH II project.

Doubling the capacity for experimental stations

To meet the demands of the user community, the FLASH free-electron laser facility is undergoing a major extension called FLASH II. Civil construction of FLASH II has started and most components have been ordered.

FLASH II includes a new undulator line in a separate tunnel and a new experimental hall that doubles the capacity for experimental stations. The design builds on experience gained during many years of user operation. It aims at the optimal transmission of shorter wavelengths (4 to 60 nm at the fundamental) to users, with the harmonics reaching the water window and beyond. To obtain increased coherence, seeding of the FEL over a large fraction of the wavelength range (from 10 to 40 nm) is added from the start.

The design of the tunnel and infrastructure has been finished. Construction started in 2011 and will continue during the major part of 2012. The electron beamline with the extraction section behind the present FLASH accelerator is almost finished and most of the components have been ordered. This includes the undulator, which will have a variable gap so that the wavelengths of FLASH I and FLASH II can be tuned independently.

The connection to FLASH is due to be realized at the beginning of 2013. This will require another major shutdown of the FLASH facility. Commissioning and first lasing of FLASH II will take the remainder of 2013 and run well into 2014. Later in 2014, the beam should be handed over to the first experimental station in the new FLASH II hall.

For the near future, space is foreseen for an afterburner at the second harmonic, a THz undulator for pump-probe experiments as well as for an additional undulator line and several experimental stations in the FLASH II hall.

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Figure 2

Layout of the FLASH II tunnel and hall

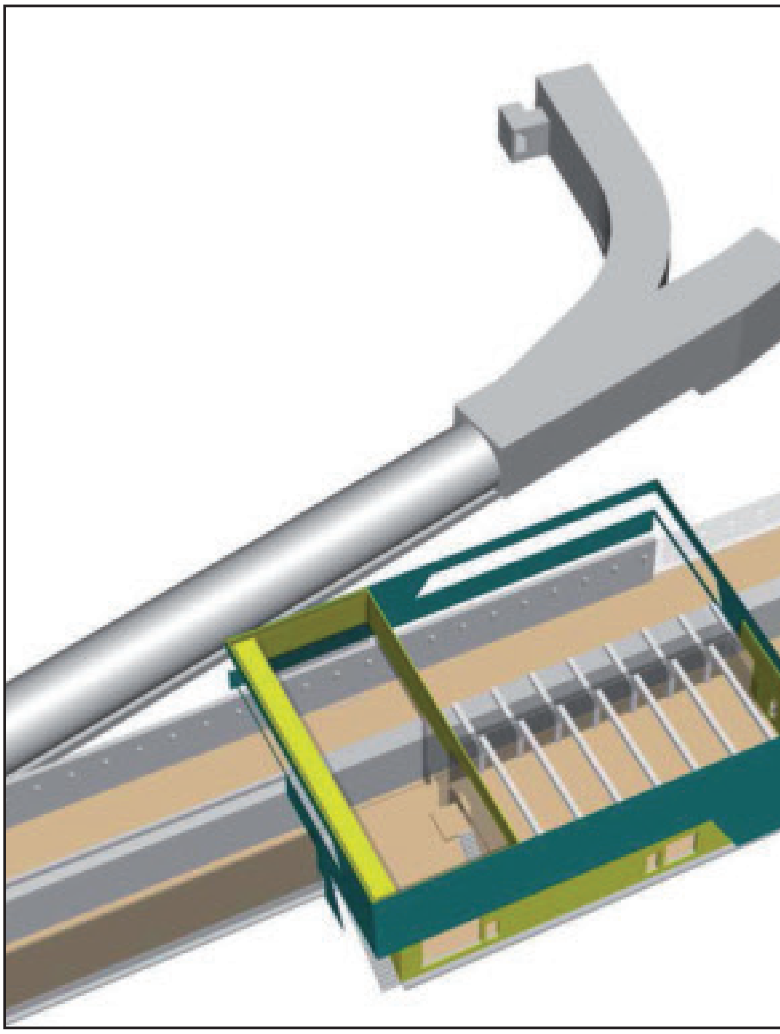
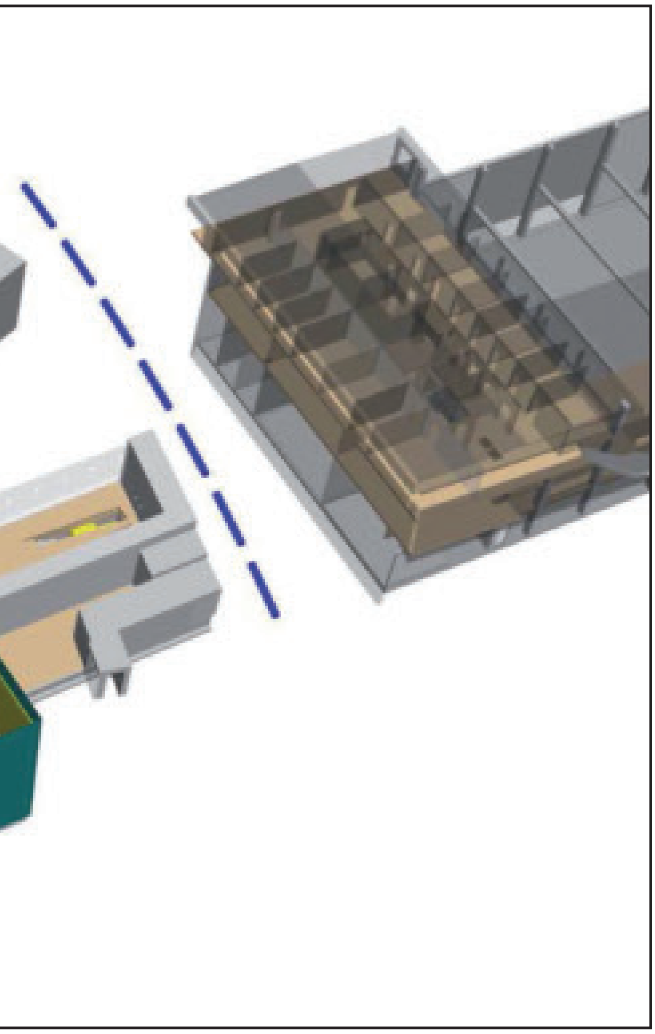


Figure 1

Civil construction of the FLASH II tunnel. Shown is the crossing of the PETRA III tunnel.



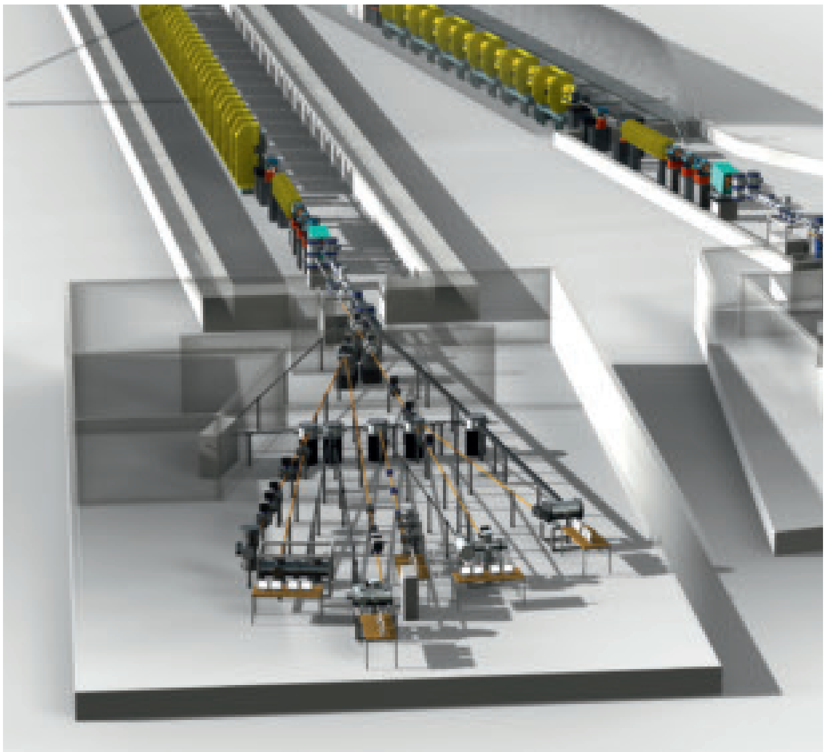


Figure 3

Layout of the FLASH II experimental hall

European XFEL.

Construction of the accelerator complex

The European XFEL, a free-electron laser in the X-ray range, is being constructed by an international consortium. Under the leadership of DESY, 17 European institutes contribute to the accelerator complex, both to the construction of the superconducting accelerator and subsequent transport systems for the 17.5-GeV electron beam and to the comprehensive infrastructure. First components have been delivered and after the accelerator tunnel breakthrough, installation of the technical building equipment is due to start soon.

Additional funds allow return to 17.5 GeV

One year ago, reducing the electron beam energy of the European XFEL to 14 GeV was discussed at length. In principle, better electron properties make it possible to achieve the light properties originally foreseen for the European XFEL at lower electron energies. Carefully conducted simulations show, as was already reported at the time, that a linear accelerator shortened by 20 accelerator modules is still suitable to achieve all the project goals. These considerations were made in the event that the funds for the construction of a 17.5-GeV accelerator could not be made available.

In mid-2011, the German and Russian delegates at the European XFEL Council announced that they would enable the full configuration to be realized through additional funding. This step was followed by the immediate adjustment of the overall project plan. All accelerator components are procured in accordance with the increased number of items. The construction of the accelerator follows the original plan. The detailed studies of the previous year corroborate an optimized working range of the European XFEL extended to short wavelengths.

First components

The accelerator complex of the European XFEL is being constructed under the direction of DESY by an international Accelerator Consortium of now 17 institutes. A project team led by the Accelerator Consortium Coordinator manages all activities. Many of the tasks within the work packages and institutes are directly visible through the delivery of first components. Prototypes can be seen in the participating institutes or on the DESY site. Regular visits to manufacturers and the exchange of knowledge and information in the context of work meetings determine the daily life of many partners. Virtually all major contracts for the manufacture of accelerator components have been awarded. Recently, all activities in connection with the construction of the accelerator complex were definitively assigned to the respective responsible institutes. The project team is complete and can carry out its many tasks in close cooperation.

One major challenge is the assembling of the 100 accelerator modules. Small and large series of up to 800 identical individual components must be provided on schedule and with appropriate quality assurance by DESY, CEA Saclay/IRFU, LAL Orsay, INFN Milano, the National Centre for Nuclear Research Świerk, CIEMAT Madrid and BINP Novosibirsk. Over a period of about two years, work is carried out with small buffers in a just-in-time

Figure 1

The Accelerator Consortium Board during a visit of the European XFEL construction site

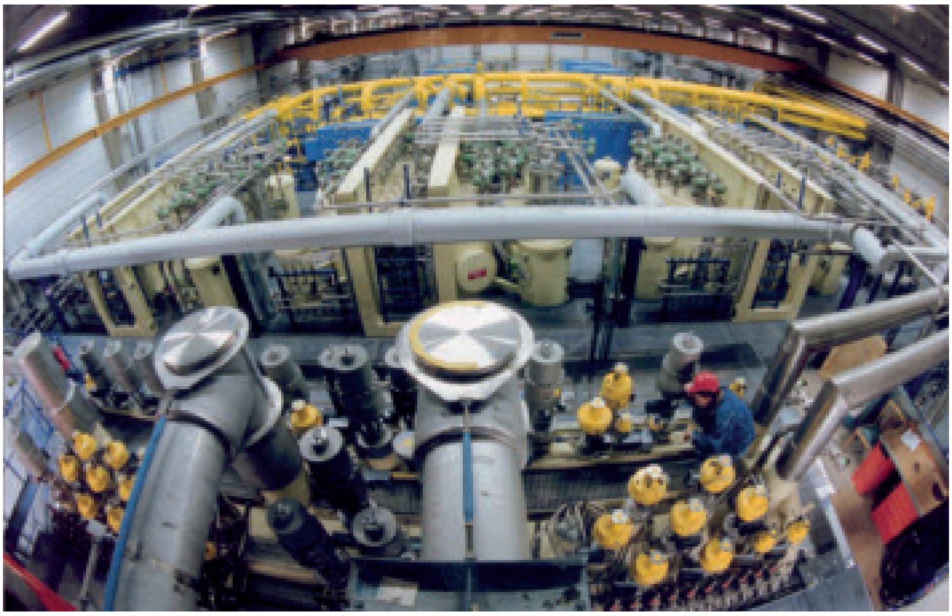


Figure 2
The former HERA refrigeration plant is being remodelled and modernized for the European XFEL.

production. Critical components such as the accelerating structures themselves are released for installation after elaborate tests only. In other cases, pre-delivery inspection at the manufacturers is sufficient. The actual assembly is done in Saclay, followed by the final test in the DESY Accelerator Module Test Facility (AMTF). Mixed teams from the participating institutes supervise the work.

The procurement of technically very sophisticated components such as RF transmitters, but also special beam diagnostics elements is possible through the strong commitment of technical experts and the specialists responsible for procurement. Tendering and contracting is realized in a close cooperation that sometimes lasts several months. The contract supervision and support then begins, which in some cases may even extend until 2014. Long manufacturing times are not uncommon in large series. Many orders that are associated with the accelerator infrastructure are carried out on a shorter time scale, however. In the AMTF area, the installation of energy supply, cooling and air-conditioning systems has begun. Many tenders for the upcoming equipment of the accelerator tunnel, ranging from lighting and construction of cable trays, through security and communication technology to tunnel vehicles, have been launched and contracts have been awarded.

As a superconducting accelerator, the European XFEL requires a suitable cooling supply. Already during the acceptance tests in the AMTF, which are performed by IFJ-PAN Cracow and DESY, both the individual accelerating structures as well as the completed accelerator modules need to be cooled to 2 K. For this purpose, the existing refrigeration plant at DESY must be rebuilt and modernized for European XFEL operation. A corresponding order has now been placed with industry. In addition, a number of transfer lines to transport the cold helium are being manufactured and installed together with sophisticated distribution boxes. Contributions in the field of refrigeration technology come from DESY, the National Centre for Nuclear Research Świerk, IHEP Protvino and BINP Novosibirsk.

An essential step towards establishing the European XFEL is the completion of the accelerator tunnel. The tunnel breakthrough took place already in the summer of 2011, further construction of the tunnel mouth and floor followed since. By the end of the year, handing over to DESY for further technical building equipment was almost reached. Already in the first quarter of 2012, first DESY groups together with the commissioned companies will begin with the installation of energy supply and security technology. The so-called pulse cables for the future supply of the RF klystrons will follow only a short time later. The installation of the actual accelerator will begin in 2013.

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REGAE.

First electrons at DESY's smallest accelerator

REGAE, the Relativistic Electron Gun for Atomic Exploration, is an electron source for time-resolved diffraction experiments that is being built within the framework of the Center for Free-Electron Laser Science (CFEL), i.e. in a collaboration of the Max Planck Society, the University of Hamburg and DESY.

Just as light behaves in the well-known way as a wave but also obeys particle properties, electrons, which are often thought of as particles, have a wave nature. Shortly after its formulation in the 1920s, this wave–particle dualism led to the development of the electron microscope by Ernst Ruska (1931). In contrast to particles travelling in a straight line, waves extend into the shadow region behind an aperture – a phenomenon called diffraction. If an aperture has several openings, partial waves going through the different openings can interfere behind the aperture. Thus, if the crest of a partial wave coincides with the trough of another partial wave they annihilate, while they enhance each other constructively at other places. The characteristic interference pattern created in this way can be described in terms of the wavelength of the incoming wave and the geometry of the aperture, i.e. the size and the distance of the openings.

At REGAE, atoms in a molecule or a crystal take over the role of the openings. The electron wave is diffracted at these "openings" and the interference pattern is recorded on a screen behind the probe. The structure of the material of the probe is then deduced from the interference pattern. Science is not just interested in the structure of a material, however, but also in dynamical structural changes as they occur in chemical reactions or phase transitions. To "film" these structural variations, the electron bunches must be compressed down to a length of about 10 fs. If the electrons then hit the probe with a defined temporal delay after the structural change has been initiated, e.g. through irradiation with a laser beam, the development can be recorded in a series of images.

Such investigations require electron bunches of extraordinary quality. The transverse emittance of the beam must be as low as $5 \cdot 10^{-3}$ µm, nearly 200 times lower than for typical free-electron laser parameters. These extreme values can only be reached at very low bunch charges well below 1 pC.

Measurements of beam properties as required for the operation of the machine and the recording of the interference pattern are challenging and entail new developments at these low charges. Another focus at REGAE follows from demanding temporal stability requirements: to sample developments with a resolution well below 100 fs, the electron bunches must hit the probe with an accuracy of some 10 fs.

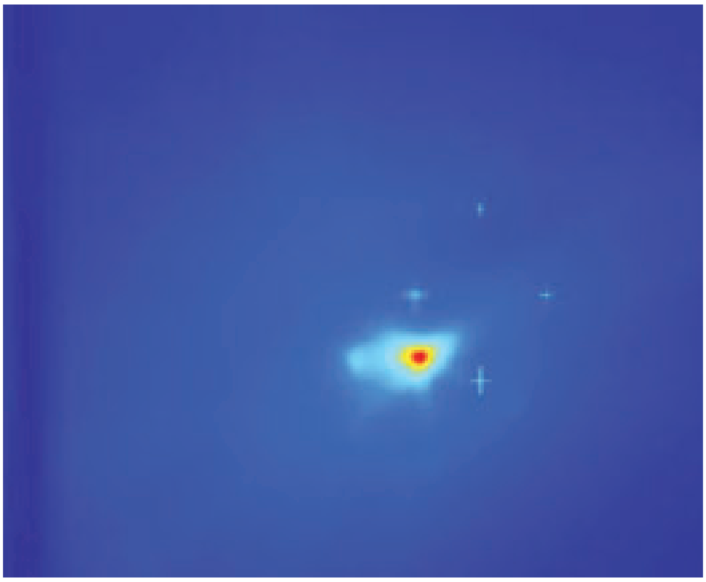

Figure 2

The first electron beam at REGAE. The calibration marks are separated by 2.5 mm. The faint spot on the left of the beam spot is a reflection.

Figure 1 shows the REGAE setup from the electron gun in the foreground up to the target chamber, still packed in plastic foil, at the end of the beamline. Two waveguides for the supply of the gun and the buncher cavity protrude into the picture from the left. Components to couple the laser beam onto the photocathode are located under the black cover on the right. After completion of the first part of REGAE at the beginning of 2011, commissioning started with the conditioning of the cavities and the RF system. After extensive tests of numerous sub-

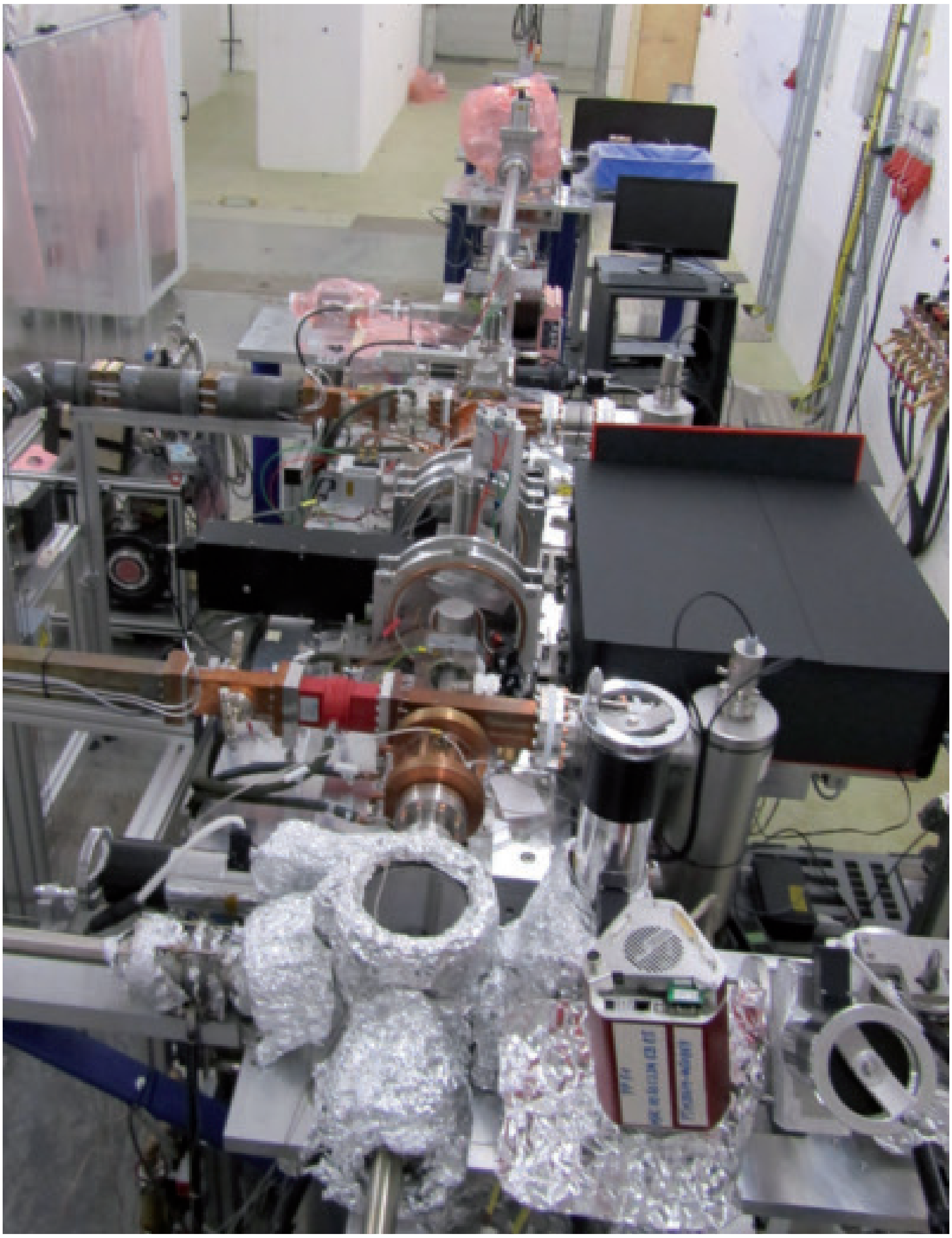

Figure 1
The REGAE beamline from the gun up to the target chamber

systems, first electrons were detected in November (Fig. 2). New screen stations based on LYSO scintillators and sensitive CCD cameras allow measuring the beam position and size at low charges. Besides Faraday cups, a cavity monitor is used for charge measurements. A record sensitivity of 10 fC was established with the cavity monitor and newly developed electronics. Design and construction of the second part of the beamline including the detector for the recoding of the interference pattern was completed. In laboratory experiments, single electron detection with high spatial resolution could be demonstrated with the detector.

The synchronization of the photocathode laser and the RF system is based on micro-TCA boards of the newest generation. REGAE takes advantage of developments for the European XFEL and FLASH projects and offers a platform for extensive tests of firm- and hardware of the newly developed components. First measurements demonstrate the expected performance. Further investigations concentrate on the stability of various subsystems. Thus a temperature stability better than 0.05°C could be established in all relevant places such as electronic racks, laser table, cavities, but also cable trays. With relative variations of 10^{-3}, the intensity and pointing of the photocathode laser also shows an exceptional performance, so that excellent conditions for the accomplishment of the project goals in 2012 are given.

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World record.

PITZ generates unique electron beam quality

The PITZ accelerator was operated during the first half of 2011, allowing a global characterization of the produced electron beams. Afterwards, a long shutdown started in which the modifications towards the PITZ2 beamline, the completion of the PITZ diagnostics setup, were realized. The machine went back into operation shortly before the end of the year.

In autumn 2010, the stage PITZ 1.8 of the photoinjector test facility at DESY, Zeuthen site, was put into operation. This stage was characterized by a new electron source (gun), a new post-accelerating cavity (booster) and a new diagnostics tool, the phase-space tomography module. The installation of a 10-MW in-vacuum coaxial coupler at the gun and the implementation of a sophisticated RF regulation system (feedback) tremendously improved the gun RF phase stability.

Between January and June 2011, an extensive optimization of the major photoinjector parameters took place, leading to the best electron beam quality (small emittance) ever produced. The optimization procedure took into account a detailed adjustment of the spot size and homogeneity of the photocathode laser pulse, the RF phase of the accelerating field in the gun, as well as the focusing magnetic field acting during the acceleration in the gun, all optimized for different operation modes with different charges of the electron bunch.

Figure 1 shows the results of transverse emittance measurements at different electron bunch charges as a function of the laser spot size at the photocathode. Lines represent published results from LCLS, the world's first X-ray free-electron laser, which started up in 2009 at SLAC in California. It is easily visible that thanks to the sophisticated optimization strategy used at PITZ, the measured emittance values are considerably reduced. This is also true compared to former PITZ results, e.g. from 2009: the transverse beam emittance decreased significantly, mainly due to major improvements of the RF stability.

In the next operation period of PITZ, it will become essential to better understand the measurement results in terms of agreement with simulations: even if theory and measurement agree fairly well at low electron bunch charges, discrepancies appear at higher bunch charge, mainly when simulating the emission process. Detailed investigations of this problem are therefore indispensable.

Figure 2

Installation of the new high-energy dispersive section in the PITZ tunnel

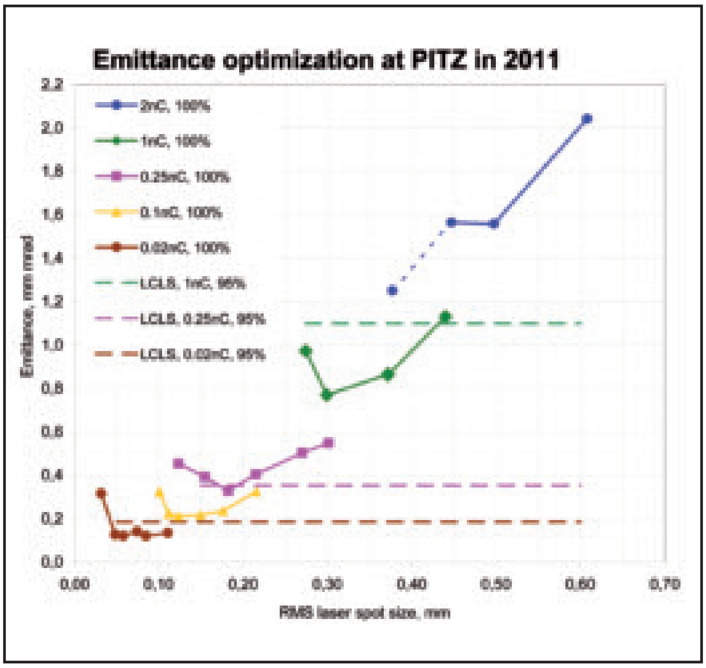
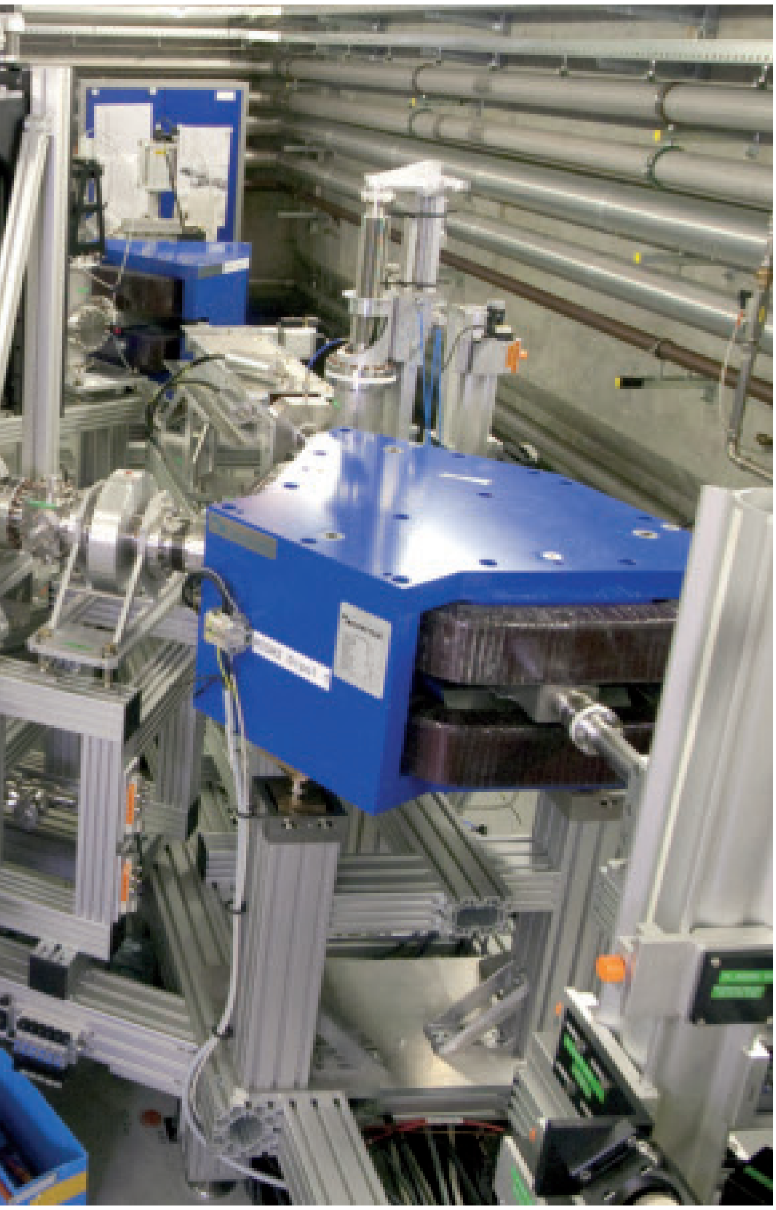


Figure 1

Emittance results from PITZ obtained in 2011: the measured emittance is shown as a function of the laser spot size at the photocathode for different electron bunch charges, and compared to results published by LCLS [1].



In June 2011, another shutdown started at PITZ, which lasted about six months and lead to the completion of the PITZ2 setup. Besides maintenance work, one main task during the shutdown was the complex installation of a high-energy dispersive section (Fig. 2) at the end of the PITZ beamline, which allows measuring the momentum distribution of long electron bunch trains with very high resolution. This section was developed and built in collaboration with LAL Orsay. In addition, a transverse deflecting cavity for time-resolved measurements of electron beam properties was installed, a contribution from INR Moscow. INR will also provide the RF system for the deflecting cavity and take care of the commissioning of the PITZ deflector, since the PITZ system is a prototype for the deflector of the European XFEL. Except for some smaller elements, e.g. missing kicker magnets, the PITZ2 setup is now realized.

In parallel to the vacuum installations in the tunnel, the gun RF system was exchanged: a more powerful Toshiba klystron together with the Thomson modulator evaluated for the European XFEL will now deliver 10 MW of RF power to the gun. This could lead to further improvements of the electron beam quality produced at PITZ.

At the end of November, the booster and later also the gun were put into operation again and conditioned. In mid-January 2012, a long measurement period with some interruptions will start at PITZ. It will presumably last until the end of 2012, when the gun foreseen for the European XFEL startup will be installed at PITZ.

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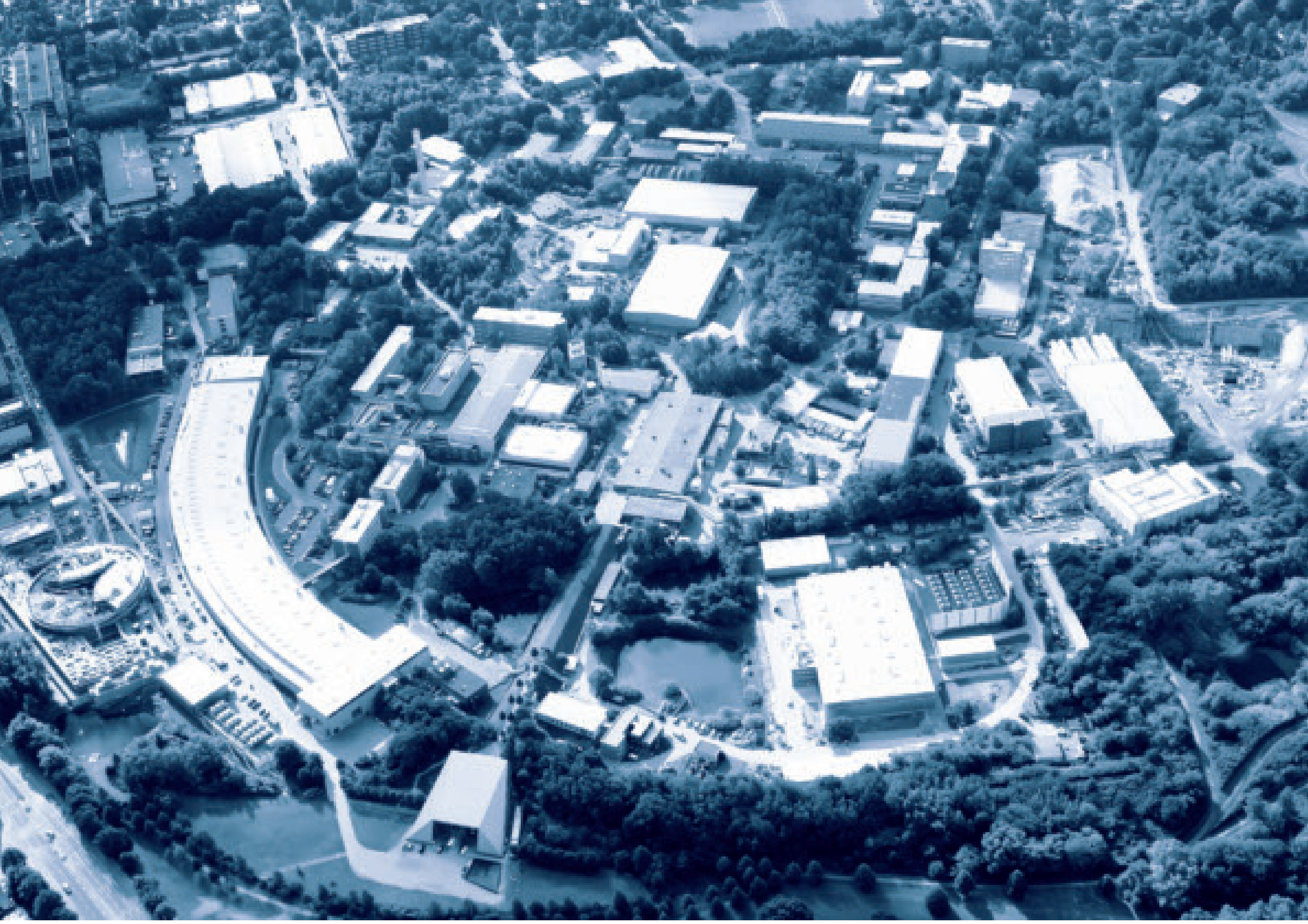

Highlights · New technology · Developments.

Future-orientated vacuum control system.

Control system concept developed for PETRA III to be used at European XFEL

During the years 2008 and 2009, when the accelerator PETRA II was converted into PETRA III, the vacuum control system was also completely rebuilt. New controllers and interface modules were developed in a close collaboration between the DESY groups MCS and MVS.
Since 2011, the PETRA III control system has also been used for the electron source REGAE. Because of the positive experience and the good results obtained during the operation time, it was decided to implement this concept at the European XFEL.

History

During the conversion of PETRA II into PETRA III, the vacuum control system was completely rebuilt. For several technical and operational reasons, profound modifications of the front-end electronics, networks, centralized control system software and system infrastructure were necessary. One of the main changes consisted in replacing the dated fieldbus SEDAC by the commercial fieldbus CANopen. The highly outdated electronic controller and interface modules were replaced by newly developed ones. The development of the new modules was based on experience gained with the control systems of the DESY accelerators LINAC II, PIA, DESY, HERA and PETRA II. It was accomplished by the DESY divisions MCS and MVS in cooperation. Because the old and new systems are compatible, old field components such as power supply units for sputter ion pumps, vacuum-measuring units and valve controllers can still be used without modifications.

The new control system was launched at the end of 2008. It has been continuously used during accelerator operations since 2009. There was no disruption of the operation mode due to a failure of the control system. Since 2011, this vacuum control system has also been successfully applied at REGAE.

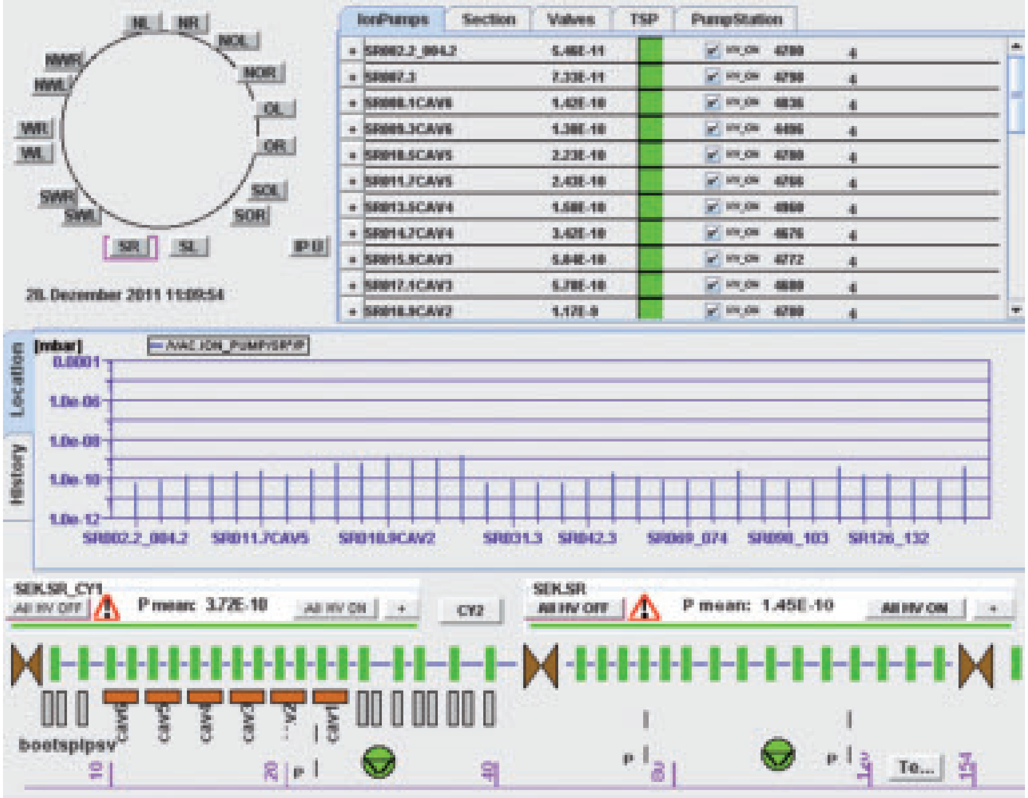

Figure 1
Input mask for the interlock thresholds

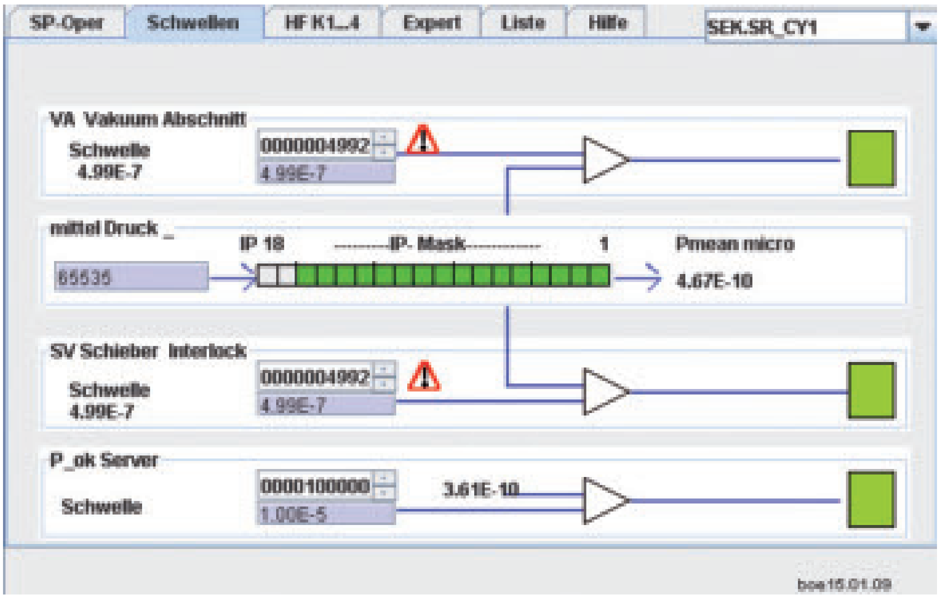

Figure 2

Vacuum control system JDDD interface, overview of PETRA III area south-right

Hardware

The vacuum system of PETRA III consists of 39 vacuum sections separated by vacuum valves. The monitoring of the vacuum and the control of the valves is done by microcontrollers in these sections. Each microcontroller converts the ion current of up to 18 sputter ion pumps into pressure values and generates interlock signals that are used by other DESY groups such as MHF and MPS. In case of accidental venting of the vacuum system or leakage, the microcontroller closes the valves to secure adjacent vacuum sections. This is done by calculating the mean pressure of the section in the microcontroller. The valves receive a closing command within 300 ms once a certain pressure threshold is exceeded. Each valve is located between two vacuum sections and is therefore controlled by two microcontrollers. This is a secure and redundant concept. The valves can be operated from the tunnel and the electronic racks in the PETRA III halls, as well as from the graphical user interface on the screen. Each section also uses a PIRANI measurement unit. This measurement provides independent information to the microcontroller on whether the system is vented or evacuated. It is used as a requirement to allow safe switching of the high-voltage power supply units of the sputter ion pumps.

The electronic components installed in the accelerator tunnel are radiation-resistant to a large degree, as they contain no highly-integrated semiconductor circuits. To protect the essential parts of the control system from power glitches and make them sustainable and reliable, uninterruptable power supply (UPS) is used.

Server / graphical user interface

The control system uses both the TINE and the DOOCS protocol. Thanks to the JDDD frameworks, graphical user interfaces (GUIs) can be designed easily and effectively. The microcontrollers work self-reliantly and do not need to communicate with the data server to control the vacuum system. The data servers have the task to link the hardware to the GUI on the computer screen. They provide the information for the visualization. Besides that, the configuration of the microcontroller is also done through the server. The control system can be operated from a notebook in the tunnel, the PCs in the electronic racks and the console in the accelerator control room. In addition, the system is accessible through the World Wide Web using an authorized account. This also facilitates the vacuum on-call service, allowing a quick diagnosis of problems and thus a faster response to the majority of problems.

All relevant vacuum data, such as pressure histories and status of components, are archived in a long-term data archive. Trouble reports, which are relevant for the operation of the accelerator, can be sent via SMS to the cell phone of the on-call service. Mobile equipment such as turbo pump cards or mass spectrometers, which are necessary for maintenance, can be integrated into the control system as well. These components can be visualized and controlled automatically. The data of these components can be stored automatically in the archive as well.

Future

From 2013 on, the system will be adopted and applied at the accelerators LINAC II, PIA and DESY II. In addition, because of the positive experience, the system will control the sputter ion pumps at the European XFEL and operate the vacuum valves in the cold linac section. For this application, the section-based logic must be converted into valve-based logic. Currently, the specific requirements of the European XFEL vacuum control system are being determined to allow for the necessary modifications of the PETRA III vacuum controller modules by the MCS group. With the proper vacuum control system at hand, it will be possible to operate the European XFEL accelerator vacuum system safely and easily.

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ILC high beam current tests at FLASH.

High beam loading RF operation with flat cavity gradient

The design for the main linac of the International Linear Collider (ILC) is based on RF stations that comprise one 10-MW klystron providing power for 26 cavities housed in three cryomodules. The average operating gradient is 31.5 MV/m with a tolerance of 20% gradient spread (i.e. individual cavities ranging from 25 MV/m to 38 MV/m). To achieve the design average operating gradient, all cavities must operate simultaneously within 3% of their respective gradient limits under full beam current conditions (6 mA baseline design, 9 mA upgrade). FLASH offers an excellent test bench for ILC operating conditions as it is also based on a single-klystron multiple-cavity scheme and allows acceleration of beam currents up to 9 mA. A series of tests is being carried out at FLASH as part of an international collaboration between DESY, Fermilab and KEK, to demonstrate operation at the limits of gradient and RF power in the presence of heavy beam loading. More specifically, the latest test took place in February 2011 as a proof of principle of tuning key cavity parameters to accelerate high beam currents while maintaining flat cavity gradients.

Challenges

In pulsed accelerators like FLASH or the ILC, the electric field inside a cavity is ramped up at the beginning of each pulse and kept constant both in amplitude and phase for the entire duration of the beam train. This latter time segment where the beam is accelerated is commonly referred to as “flat top”. To meet the luminosity goals, the flat-top gradient is regulated and controlled to better than 0.1% in amplitude and 0.1 degrees in phase, according to ILC specifications.

At FLASH, as in the ILC design, one klystron provides power to several cryomodules. Due to performance disparities among cavities, the klystron RF power is distributed according to the individual cavity gradient limits, i.e. cavities with higher performance will receive more power than cavities of lower performance. At FLASH, this is achieved by using adjustable power couplers, which are set once according to each cavity’s performance. The spread in power distribution results in a gradient spread among the cavities within a cryomodule. A consequence of this gradient spread is the different behaviour of each cavity due to the interaction with the beam, which is also known as “beam loading”. Typically, cavities operating above the average gradient will show an increase in gradient (positive tilt), while those operating below average will see their gradient drop during the beam acceleration (negative tilt). While this effect is negligible for low beam currents (below 1 mA), it can induce 10 to 20% tilts on single cavities for high beam currents such as the 9 mA ILC upgrade design, as illustrated in Fig. 1. It was demonstrated that a physical misalignment of cavities combined with a gradient tilt during beam acceleration results in a transverse dispersion of the beam. Due to mechanical limitations, a perfect alignment of all cavities in the accelerator chain is not realistically achievable, leaving only the option of minimizing the cavity tilts to avoid this detrimental beam dispersion effect.

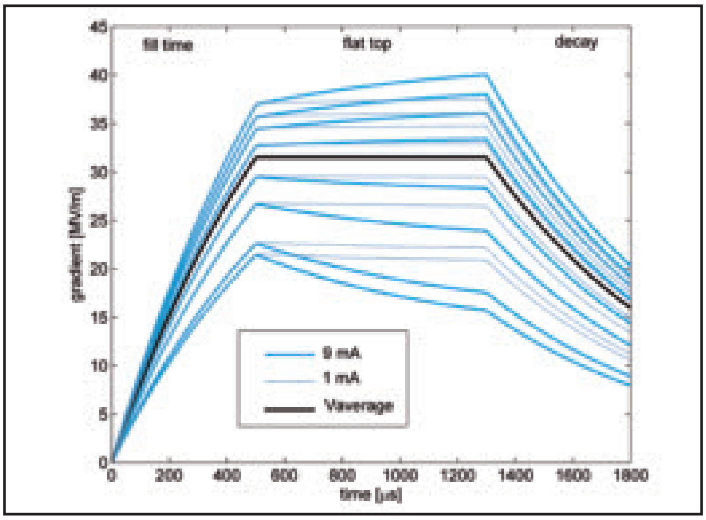

Figure 1

Pulsed cavity gradients for one cryomodule with 1 mA (dashed) and 9 mA (solid) beam currents, illustrating positive and negative tilts during the flat-top region. The average gradient is shown in black.

For a multi-cavity single-klystron accelerator like FLASH or the ILC, the fields of all individual cavities are measured and added up. The feedback control then computes the amplitude and the phase of the sum of all cavity gradients, and regulates the drive of the klystron power to maintain a flat and stable total field accelerating the beam. This control scheme is referred to as “vector sum control”. It was first used on a large-scale superconducting accelerator at FLASH. One limitation of this scheme is that it does not offer control over individual cavity gradients, but only over the sum of all the gradients because the same klystron provides power for all cavities. Any attempt to lower the main drive power to flatten the flat top for cavities showing a positive tilt will also worsen the negative tilt of the other cavities.

ILC high beam current tests at FLASH

The FLASH facility offers an excellent test bench for the ILC R&D effort, where key technological concepts can be experimentally implemented and their feasibility verified. One technical challenge is to find a solution for accelerating high beam currents (9 mA) using the vector sum control scheme, while maintaining flat gradients for individual cavities. This was one of the goals of the last 9 mA run at FLASH, which took place in February 2011.

Cavity gradients can be flattened by adjusting the forward power distribution and the power coupling to individual cavities, i.e. the “loaded quality factor” (Q_L). Changing the power ratio for each cavity at FLASH would require a substantial mechanical intervention and could not be accommodated within the scope of the ILC tests. However, it was demonstrated that by acting only on the cavity Q_L, a similar gradient-flattening effect could be achieved, but with more restrictions. This principle was first simulated and successfully implemented during the last ILC high beam current run at FLASH. The outcome of this test was a moderately high beam current acceleration (4.5 mA being the maximum achievable at the time) for a 400 μs flat top, while maintaining the individual cavity gradient flatness to better than 1%, solely by modifying the corresponding Q_L values.

The test at FLASH was carried out on the last two cryomodules of the accelerator (ACC6 and ACC7), which contain the cavities with the highest gradient performance and are equipped with motorized controllers of the cavity loaded *Q*. Using a standard cavity model, one can calculate a set of Q_L values which would provide flat gradients for all cavities at a given beam current with the existing power distribution. At FLASH, all cavities are normally set to the same quality factor $Q_L = 3{\cdot}10^6$, ensuring flat gradients for no beam or typical beam currents for normal FLASH operation (≤ 1 mA). For flat gradient with higher currents, the calculated Q_L values range from $1{\cdot}10^6$ to $4.5{\cdot}10^6$, depending on the cavity operating gradient. All sixteen cavities of ACC6 and ACC7 were adjusted with these “optimized” Q_L values and the beam current was then ramped up to the matched beam condition.

In Fig. 2, gradient tilts for the cavities of cryomodule ACC7 are calculated over the 400 μs flat top and plotted as a function of beam current, during the ramp-up from 0 to 4.5 mA. As expected, individual cavity tilts decrease as the beam current is increased, until the current for which the Q_L values were optimized is reached. While the target matched current was 4.5 mA, cavity tilts actually went through a minimum around 4.2 mA. This illustrates some of the limitations encountered during the test, namely the accuracy with which one can measure and control the cavity loaded *Q*. While simulated values provided perfectly flat gradients, estimated measurement uncertainties of the order of 2–3% in addition to systematic errors resulting from the motorized Q_L tuners explain both the spread and the offset among the cavity tilts at the target matched current.

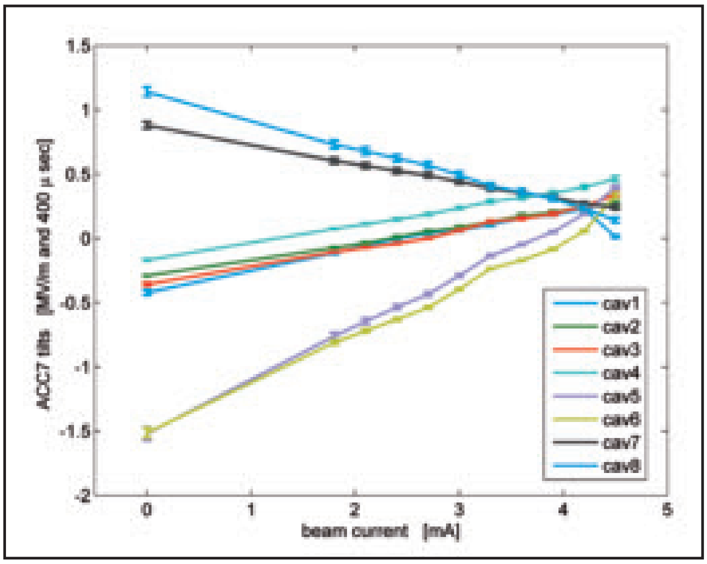

Figure 2

ACC7 cavity gradient tilts, measured during a 400 μs flat top, as a function of beam current. The loaded *Q* values were optimized for minimal tilt at 4.5 mA beam current.

Future steps

Cavity power ratios, operating gradients, loaded quality factors and beam current are intrinsically coupled in the flattening gradient calculations and cannot be changed independently without affecting the cavity gradient profile. At FLASH, the power ratios are fixed, which imposes constraints on the optimization calculations of loaded *Q* values for flat beam loading. Furthermore, mechanical restrictions on the motorized Q_L tuners define an upper and a lower bound on their tuning range. For this reason, theoretical solutions to flatten beam loading for currents only up to 6 mA were found to be implementable at FLASH.

Another limitation of the present approach is that each set of optimized Q_L values is valid only at a given current. As a consequence, operating at a lower or higher beam current will still produce individual cavity tilts. This raises another challenge for the ILC, where cavities must operate within 3% of their maximal gradient. A slight positive tilt due to a mismatch between beam current and optimized loaded *Q* can be enough to bring the cavity gradient above its critical limit, causing potential damage to the cavity and accelerator downtime. One of the goals for the next ILC high-current test at FLASH, scheduled for February 2012, is to improve the accuracy and automate the optimization of Q_L and to investigate various tuning strategies linked to operational scenarios such as beam current ramp-up, shortening of the RF pulse, or machine turn-on sequence.

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High-speed processing.

First European-XFEL-like MicroTCA-based LLRF system at FLASH

The requirements for the short- and long-term phase and amplitude stability of the 1.3 GHz accelerating field for the European XFEL are below 0.01 degrees and 0.01%. A new low-level radio frequency (LLRF) system, based on the MicroTCA standard and using approved 19" modules, has been tested at FLASH, which is considered the test bed for the European XFEL. First measurements in the FLASH injector section showed an excellent beam energy stability of 0.005%, which meets the tight requirements for the European XFEL injector systems.

A sophisticated low-level radio frequency (LLRF) control system is planned for the European XFEL to meet the stringent short- and long-term phase and amplitude stability requirements for the 1.3 GHz accelerating field, which are below 0.01 degrees and 0.01%. At FLASH, an energy stability of 0.005% has been demonstrated using the VME electronic crate standard, but since the underground European XFEL rack space near the cavities is limited, the LLRF design must be more compact than the FLASH design. In addition, the system must be capable of processing a larger number of cavities in real time. A prototype European XFEL LLRF system has been developed using the new industry standard MicroTCA.4, which has recently been approved by the PICMG consortium. The new system has been tested at FLASH to verify the stability.

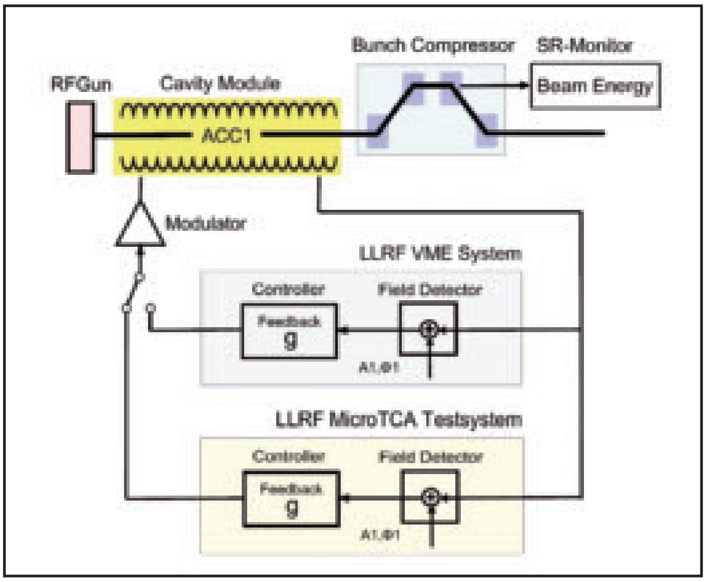

Figure 1

First MicroTCA LLRF system installed in the injector section at FLASH

European-XFEL-like LLRF system tests at FLASH

Figure 1 shows the layout of the first LLRF high-frequency MicroTCA test system installed in the injector section at FLASH. The LLRF station processes probe, forward and reflected signals for the eight cavities of the ACC1 accelerator module. The amplitude and phase are measured through down-conversion and digitization of the 1.3 GHz cavity signals. The vector sum of all cavity signals is processed and regulated using an FPGA that drives the high-power klystron by up-conversion. The beam energy stability of the injector can be measured using a synchrotron radiation monitor after the first bunch compressor.

LLRF MicroTCA prototype system

The LLRF system should be robust, maintainable, easy to service, low-cost and scalable in performance. Design resources should be shared among DESY, industry and collaboration partners. The LLRF group decided to package the European XFEL systems in the new MicroTCA standard. All modules are compatible with the new MicroTCA.4 standard, which additionally offers a rear transition module (RTM) zone for signal conditioning and a clock, trigger and interlock signal distribution via the advanced mezzanine card (AMC) backplane. Figure 2 shows the LLRF system packaging and rack layout as installed in the FLASH injector hutch.

Long-term stable 3/8" Heliax high-frequency cables carry the cavity signals to a 19" module for signal calibration by injecting the reference. Local oscillator signals for the down-conversion are generated in the LOGModule. The cavity pickup signals are down-converted from 1.3 GHz within RTMs of the MicroTCA crate and digitized in MicroTCA AMCs (two-sized advanced mezzanine cards) processing the cavity partial vector sums. For the added short-term amplitude and phase stability of a single down-converter channel, we achieved less than 0.005 % and 0.005 degrees, respectively less than 10 fs in a bandwidth of [10 Hz, 1 MHz].

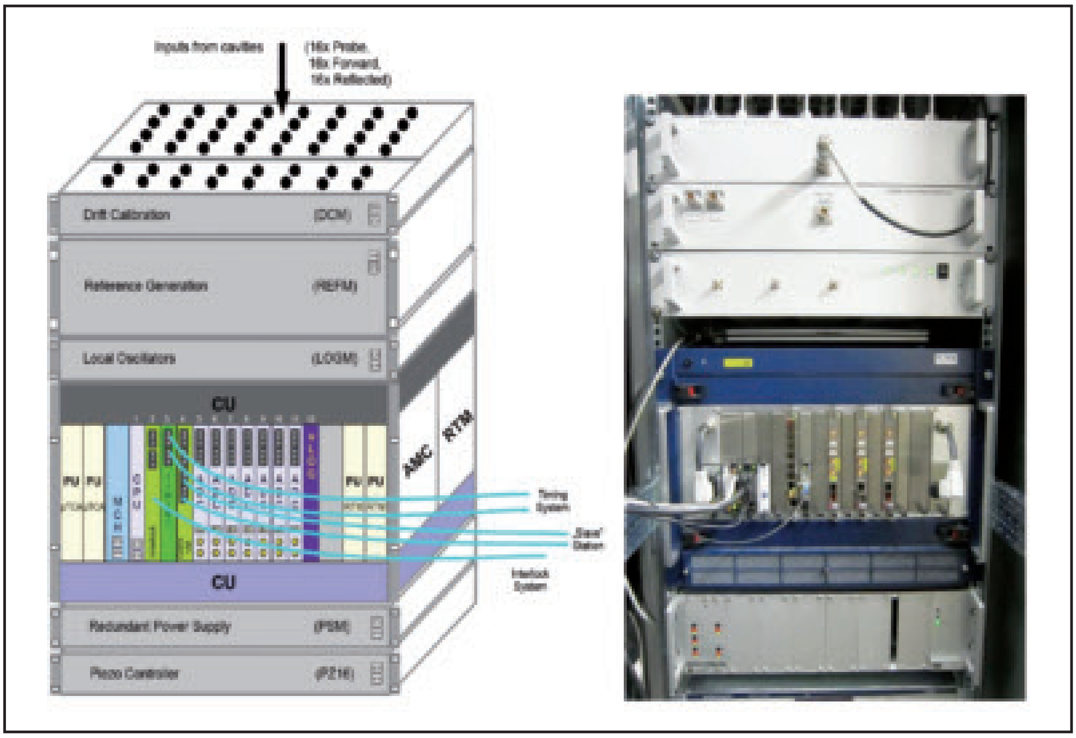

Figure 2

Layout and installation of the rack packaging of the European-XFEL-like MicroTCA-based LLRF system at FLASH

LLRF MicroTCA measurements at FLASH

Figure 3 is a screenshot of the LLRF operation control for the ACC1 module. The display shows the cavity field vector sum amplitude and phase during the FLASH beam macro-pulse. The cavity field is regulated to be completely flat using sophisticated feed-forward and feedback algorithms in the MicroTCA controller.

As depicted in Fig. 4, measurements from the synchrotron radiation camera 3BC2 located after the first bunch compressor showed a shot-to-shot beam energy stability of 0.005% (rms), which fulfils the tight requirements for the European XFEL LLRF injector systems.

As a means of improving system robustness, operation flexibility, failure diagnostics and failure handling, in the near future the new LLRF system will be installed as an upgrade in all FLASH stations and several experiments, e.g. AMTF, CMTB, REGAE and TDS.

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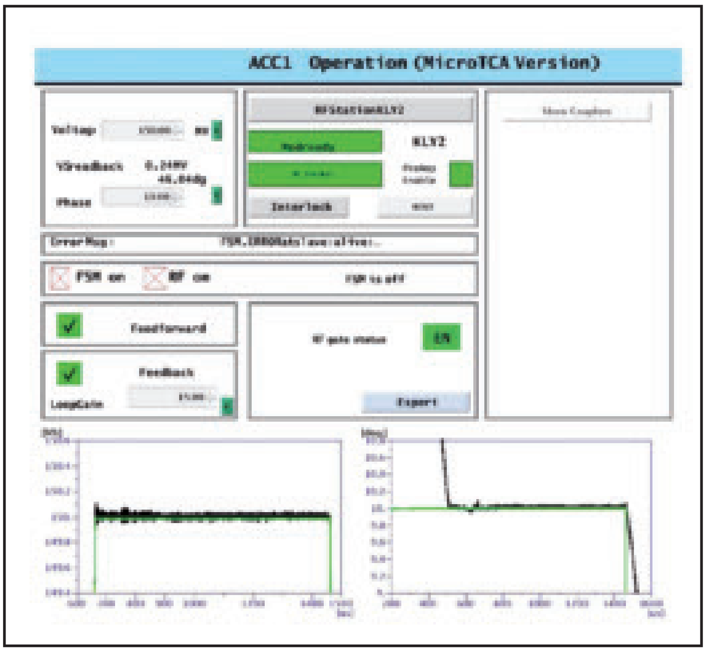
ACC1 Operation (MicroTCA Version)

Figure 3

Screenshot of ACC1 LLRF module operation control. Regulated amplitude and phase of the cavity field vector sum during the beam macro-pulse.

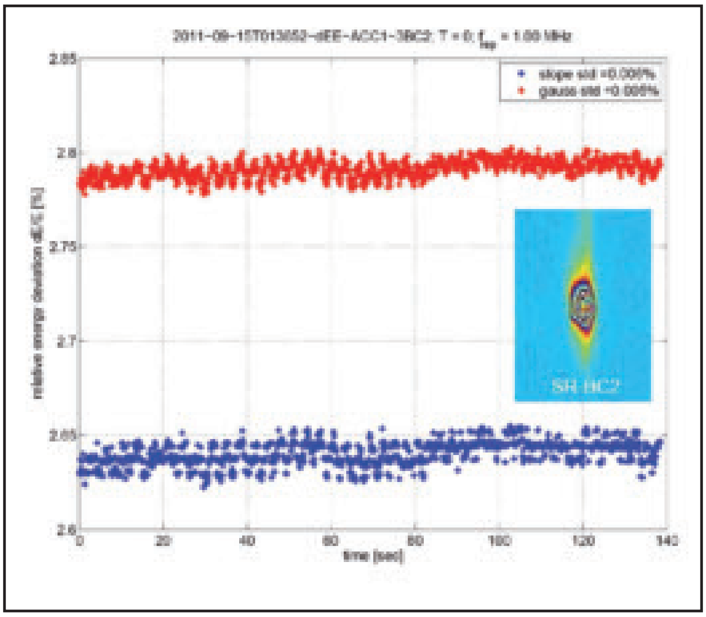

Figure 4

The shot-to-shot beam energy stability monitored by the synchrotron radiation camera in the bunch compressor amounted to 0.005% when the energy shift was determined by fitting a Gaussian curve to the horizontal bunch profile (red points), and to 0.006% when the energy shift of the bunch profile rising edge (blue points) was used.

Breakthrough in laser-to-RF conversion at FLASH.

Development of femtosecond timing techniques

Free-electron lasers like FLASH and the European XFEL require high-precision synchronization of the accelerator RF with a pulsed optical timing reference that is distributed across the entire kilometre-scale facility. For this purpose, a technique to phase-lock local RF sources to an optical pulse train with femtosecond accuracy has been invented. The technique has been demonstrated with an opto-microwave coupling device and an ultralow phase noise RF source operating at a frequency of 1.3 GHz. In this arrangement, the laser-to-RF phase detector is insensitive to amplitude fluctuations of the optical reference pulse train, allowing the detector to achieve femtosecond precision over long time periods.

Ultrashort, high peak current electron bunches are required for free-electron lasers like FLASH and the future European XFEL. The length scale of these bunches has increased the demands placed upon the accelerator synchronization, moving from a requirement of picosecond (10^{-12} s) to femtosecond (10^{-15} s) accuracy. To meet these synchronization goals, optical synchronization techniques have been employed and intensively researched throughout the past seven years. A breakthrough improvement in RF extraction from the optical reference was achieved recently. The new technique demonstrates femtosecond short-term and long-term accuracy.

The optical synchronization system is comprised of a passively mode-locked master laser oscillator emitting pulses with a repetition rate of 216.7 MHz. The laser pulses from the master laser oscillator are distributed through optical fibre links to various end stations within the accelerator facility. Since the propagation time of the optical pulses through the optical fibres changes with temperature, humidity and mechanical vibrations, the propagation round-trip time is measured and actively stabilized. At the end stations, the laser pulses are used to:

- determine the electron bunch arrival time,
- synchronize external optical lasers and
- provide ultrastable RF microwave signals for the low-level RF (LLRF) control of accelerator structures.

The simplest technique to extract an RF signal from the optical reference is to impinge the laser pulses onto a broadband photodetector. Since the laser pulse duration is typically below 1 ps (FWHM), harmonics of the laser pulse repetition rate can be extracted using narrow-bandpass RF filters and low-noise RF amplifiers. Unfortunately, this direct conversion method will drift and jitter by 10 to 100 fs due to environmental changes and AM-PM conversion. AM-PM conversion describes how amplitude modulation (AM) of the optical signal translates into an undesired phase modulation (PM) of the extracted RF signal.

To provide a robust method with sub-10 fs RF phase stability, a new technique has been successfully tested. This laser-to-RF phase detector is used within a phase-lock-loop (PLL) to lock an ultralow-noise 1.3 GHz RF oscillator to the laser pulse train, which has a repetition rate equal to the sixth sub-harmonic of the RF frequency.

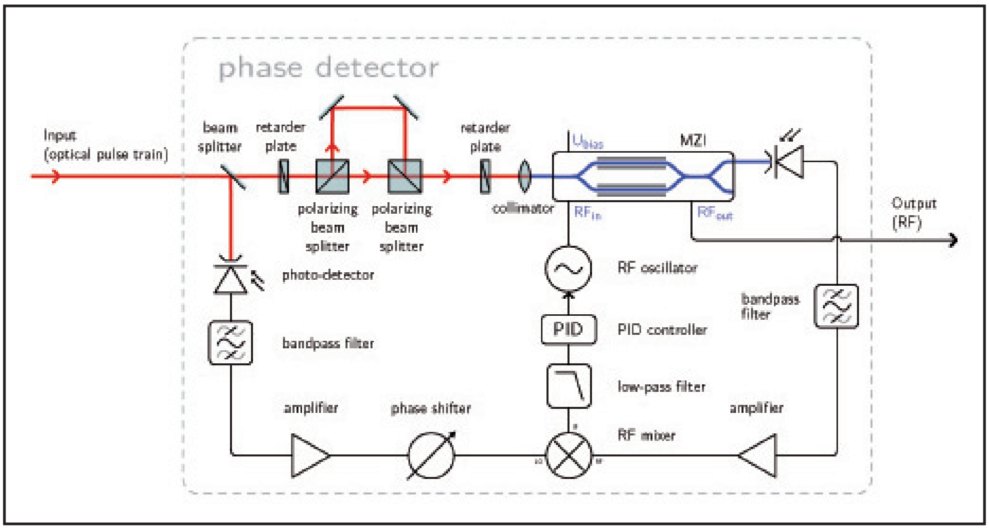

Figure 1

Scheme of the experimental setup for locking an RF oscillator to an optical pulse train from a laser

Figure 1 shows the phase detector arrangement. Half of the reference laser pulse train is split off, delayed and then recombined with the reference pulse train in a polarizing beam cube. Then both laser pulse trains are sent into an optical-to-RF amplitude modulator which is composed of a Mach-Zehnder interferometer (MZI). The MZI is biased such that half of the optical power is transmitted. One harmonic of the laser repetition rate is chosen for detection. The optical delay is adjusted so that the chosen harmonic extracted from each pulse train interferes destructively. If the amplitude of both pulse trains is equal, the harmonic vanishes entirely.

If an RF signal is fed into the RF port of the MZI, the laser pulse amplitude will vary in proportion to the RF voltage applied to the modulator. The RF voltage is thus transcribed onto the optical power of the two laser pulse trains. Now, for certain optical delays one laser pulse train hits the RF signal at 0°, while the other laser pulse train hits at 180°. Small RF phase deviations will lead to a positive amplitude modulation for one pulse train but a negative amplitude modulation for the other. The unequal amplitudes of the two pulse trains cause the harmonic to reappear.

For detection, the photodetector signal containing the chosen harmonic is down-mixed to baseband and fed into the feedback controller of the PLL. The PLL controls the phase of the RF oscillator so that the harmonic always vanishes. Variations of the optical input power affect both pulse trains simultaneously, but have no influence on the destructive interference of the harmonics.

To prove the performance of the setup, two laser-to-RF phase detectors were built and measured against each other. The first detector was used to lock the RF oscillator to the optical pulse train and the second detector was used for an out-of-loop measurement. Figure 2 shows a residual error of 14.9 fs (peak-to-peak), recorded over 40 hours. The main contribution of this error is related to a difference in the fibre length at the input of the two detectors. Changes of a few percent in humidity delay the incoming pulse train unsymmetrically. Much shorter fibres will address this issue in the future.

Figure 3 shows that the residual timing jitter between the locked 1.3 GHz RF oscillator and the optical reference amounts to only 2.3 fs, with a detector noise floor of 1 fs. The voltage-to-time conversion factor is 1.2 V/ps. Using this conversion factor, the baseband voltage spectral density at the output of the phase detector (upper plot) can be converted to timing jitter (lower plot).

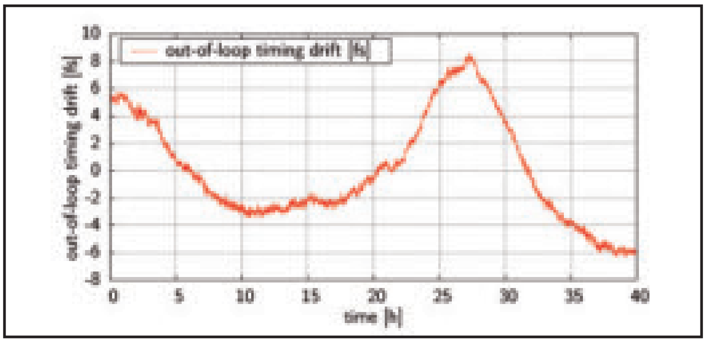

Figure 2

Residual drift of 1.3 GHz RF source locked to a laser

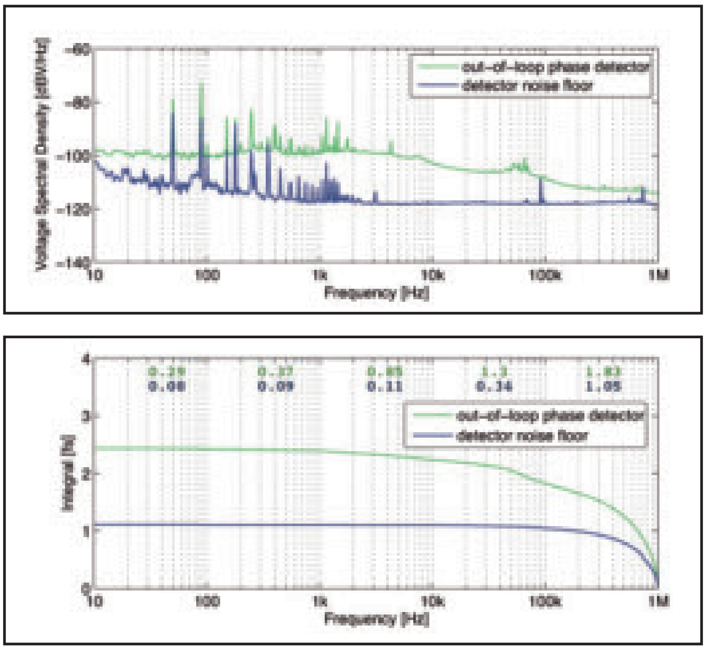

Figure 3

Residual phase error of the RF source locked to a laser. The upper plot shows the voltage spectral density of the out-of-loop detector. The lower plot shows the integrated timing errors for different decades. The blue curve shows the detector noise floor, the green curve the achieved lock performance of the RF source.

The insensitivity to variations of the optical power makes this a major improvement over previously used techniques. For FLASH, this setup will be installed in autumn, providing a dramatic improvement in RF phase stability for the low-level RF down-converters. This will substantially enhance the short- and long-term stability of the FEL operation.

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High-resolution standard beam current monitor.

Improved beam current monitors for European XFEL and FLASH

The standard beam current monitors for individual bunch charge measurements have been significantly improved to prepare for the demanding specifications of the European XFEL and FLASH accelerators. Despite a resolution and sensitivity enhancement by a factor of 50, the new device is now simpler and cheaper to manufacture.

Description

Beam current monitors of the toroid type are standard equipment in linear accelerators to measure the individual bunch charge. The resolution of these devices was typically on the order of 2 to 3 pC rms, which was sufficient for bunch charges in FLASH on the order of 0.5 to 2 nC. There is now a tendency to operate the European XFEL and FLASH at very low charge, down to 20 pC. An improvement of the entire signal chain was necessary to get reasonable results at these low charges. Figure 1 shows the “heart” of the monitor that was designed by the MDI group. It consists of a toroidal ferrite core equipped with copper windings. This assembly surrounds a short ceramic gap of the beam pipe. The whole assembly is a transformer, where the beam acts as the primary “winding” and the copper stripes are the secondary windings.

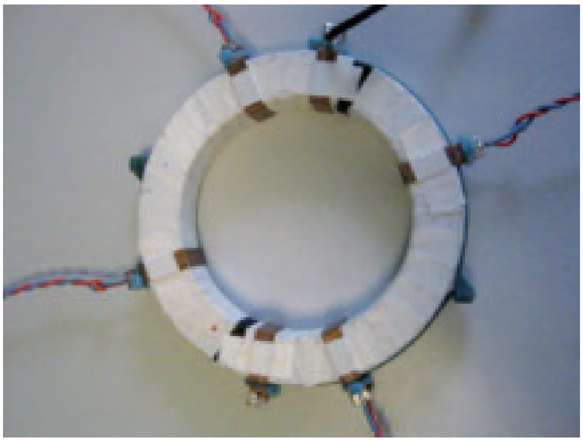

Figure 1

Ferrite core with two test windings and four output windings

Four copper strips are used as signal outputs, two strips serve as test inputs. The four signal outputs are merged by a combiner and fed into a nearby preamplifier. This setup reduces the dependence of the signal amplitude on the beam position. The signal is then routed by a 10 to 100-metre-long cable to an ADC module, which connects the device with the control system.

Improvement

This improvement was done in three steps: Step 1 involved the impedance matching of the four output windings to the attached cable. The output impedance of a transformer driven by a high-impedance source like the beam is a function of the frequency. Depending on the application, two principal optimizations are possible: optimization for flat frequency response (matching at low frequencies, see blue line in Fig. 2) or optimization for high output signal (matching at high frequencies, see red line). In our case of relatively short bunches and relatively long bunch distances, a flat frequency response is not necessary, so a change from matching at low frequencies to matching at high frequencies was possible to improve the available output power. This was done simply by removing an integrated impedance transformer (Fig. 3). This results in a gain of 20 dB in signal strength, saving the manufacturing effort for the transformer at the same time. Step 2 consisted in optimizing the loss of the combiner that merges the four output signals from the toroid. The loss could be reduced from 6 dB to below 1 dB, which is a further improvement of approximately 5 dB. Step 3 was a noise optimization of the preamplifier. With some improvements of the impedance and frequency range matching, an additional gain of 9 dB was achieved. As a final result, the sensitivity was improved by 34 dB, which corresponds to a factor of 50 in voltage amplitude.

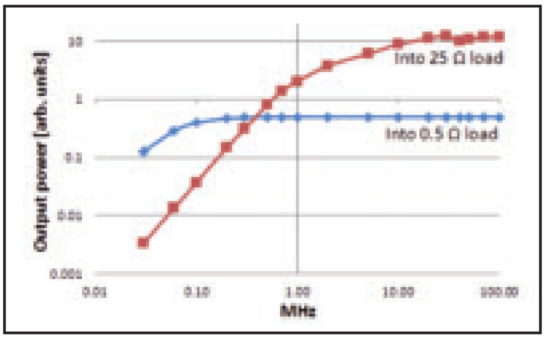

Figure 2

Output signal versus frequency for two matching schemes

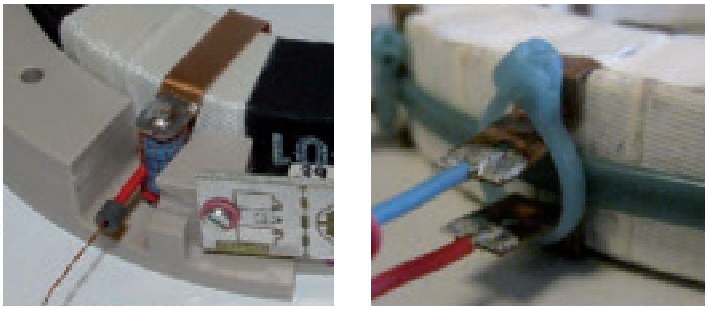

Figure 3

Output winding with transformer (left) and directly coupled (right)

For a first demonstration of the improvement, signals from the old system were compared to signals from the new system in the lab. A short charge pulse of 10 pC was injected into a test winding by a pulse generator to simulate a bunch of this charge. Figure 4 shows the response of the old monitor. In Fig. 5, the dramatic improvement is visible for the new system using the same stimulus signal.

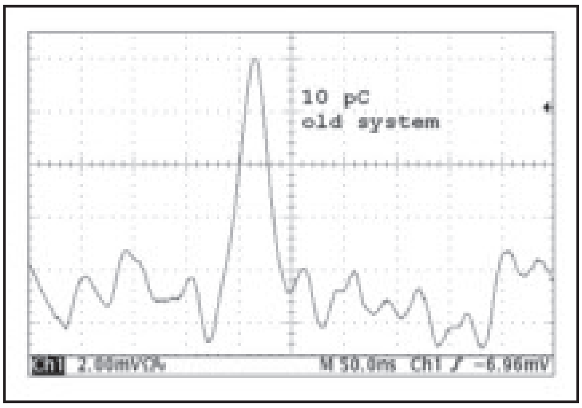

Figure 4

Lab test with a 10 pC pulse from the old system

Figure 6 shows that even for bunches with a charge as low as 1 pC, a clean measurement is possible. The estimated possible resolution with this setup is 0.04 pC rms.

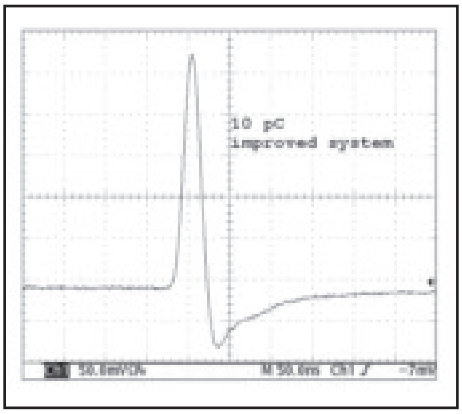

Figure 5

Lab test with a 10 pC pulse from the improved new system

Figure 7 shows a first measurement in the FLASH accelerator at a bunch charge of 8 pC. While the bunch response signal from the old monitors (upper two traces) is hardly visible, the signal from the new monitor (green trace) is comparatively clear. The noise still visible on the green trace is caused by a ground loop which has been removed recently.

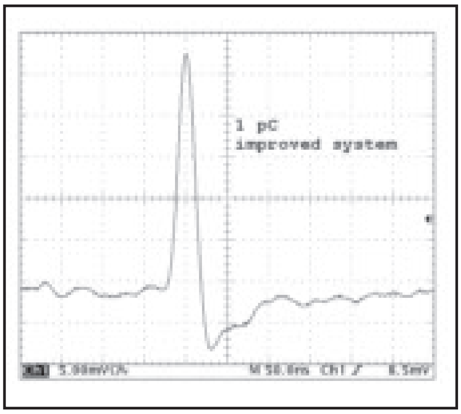

Figure 6

Lab test with a 1 pC pulse from the improved new system

So the improved standard beam current monitor will be able to measure even the smallest bunch charges at the European XFEL and FLASH (20 pC) with the necessary resolution. Up to now a measurement in this charge range was only possible with the comparatively complex and expensive cavity monitors.

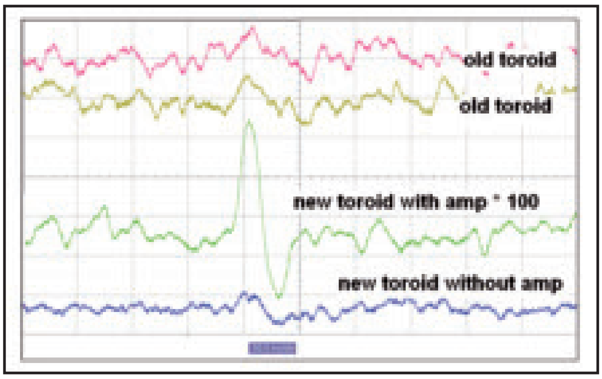

Figure 7

First measurement in FLASH with 8 pC bunch charge

I would like to express my thanks to Jorgen Lund-Nielsen, Reinhard Neumann and Norbert Wentowski for their indispensable support.

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Beam diagnostics in superconducting accelerating cavities.

Extraction of transverse beam position from beam-excited dipole modes

We demonstrated the feasibility of beam position diagnostics using higher-order mode (HOM) signals in the third-harmonic superconducting cavities at FLASH. Useful features for beam diagnostics were found for various dipole modes.

The amplitude of electron-beam-excited dipole modes has a linear dependence on the transverse offset of the exciting bunch from the cavity axis. Such modes can therefore be used for beam position diagnostics without additional vacuum components. At FLASH, we plan to make use of HOMs for beam diagnostics in third-harmonic cavities. To achieve this, special electronics is required, which is currently being designed. Prior to developing electronics, it is essential to characterize the dipole modes and understand their behaviour as a function of beam offset. For this purpose, we conducted HOM measurements, both with and without beam excitations. Simulations of the cavities were also performed.

HOMs in third-harmonic cavities

To optimize the bunch compression process, third-harmonic cavities operating at 3.9 GHz were installed in FLASH, which linearize the energy spread of the electron bunch induced by the 1.3 GHz cavities. The cryomodule ACC39 comprises four interconnected 3.9 GHz cavities (Fig. 1)

Due to the relatively small size of the 3.9 GHz cavity (scaled down from 1.3 GHz cavity by a factor of 3) and the larger-diameter beam pipes connecting the cavities (larger than one-third of those of the 1.3 GHz cavity), the HOM spectrum (Fig. 2) is significantly more complex than that of the 1.3 GHz cavities.

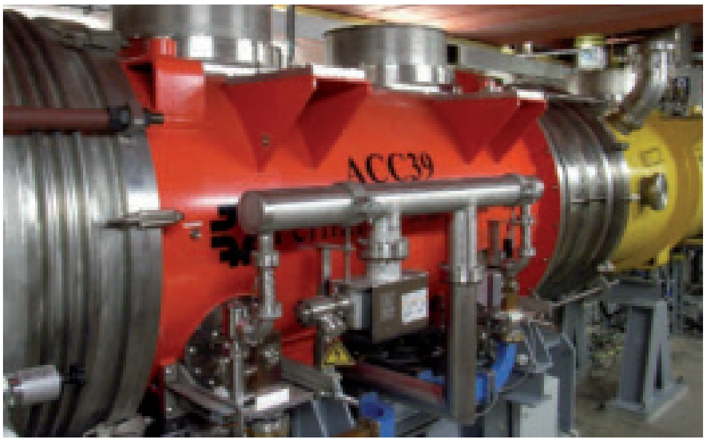


Figure 1

The red module ACC39 at FLASH contains four third-harmonic cavities. The yellow module on the right is ACC1. The multibunch beam travels from right to left.

The fundamental passband can be clearly identified in Fig. 2(a) in the range of 3.7 to 3.9 GHz. Most of the HOMs are able to couple to adjacent cavities. The strongly coupled modes lie in the first two dipole passbands (with a frequency span of 4 to 5.6 GHz as shown in Fig. 2(a)). Localized dipole modes are beam pipe modes at approximately 4.1 GHz (black curve in Fig. 2(a)) and trapped cavity modes in the fifth dipole passband at approximately 9 GHz (black curve in Fig. 2(b)). An eigenmode simulation of an ideal cavity without couplers shows the localization of these modes. This simulation reveals that the electromagnetic energy is deposited mainly in the beam pipes and end-cells (Fig. 3(a)) or inside the cavities (Fig. 3(b)). Figure 3(c) shows one strongly coupled dipole mode from the second dipole

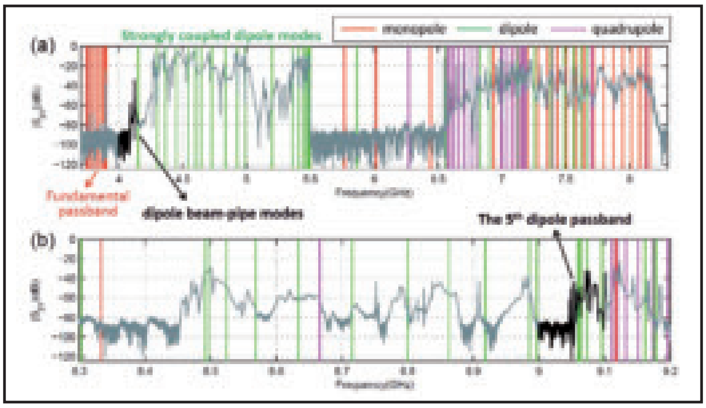
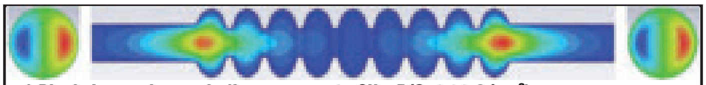
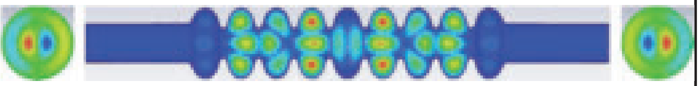


Figure 2

Measured HOM spectrum of a third-harmonic cavity. The vertical lines indicate simulation results of an ideal cavity.



a) Dipole beam pipe mode (frequency: 4.15 GHz, R/Q: 1.31 Ω/cm²)



(b) Mode from the 5th dipole passband (frequency: 9.06 GHz, R/Q: 2.17 Ω/cm²)

(c) Mode from the 2nd dipole passband (frequency: 5.42 GHz, R/Q: 50.92 Ω/cm²)

Figure 3

Electric field distributions from simulations of ideal cavities passband. The electromagnetic energy is distributed along the entire four-cavity string, which indicates that the mode is propagating amongst all the cavities in the chain.

Linear dependence on beam position

A dipole beam pipe mode at approximately 4.1183 GHz was measured at ten different horizontal beam positions, as shown in Fig. 4(a). Variations of the mode amplitude with respect to the horizontal beam position can be observed. Figure 4(b) shows the amplitude of each mode as a function of the horizontal beam position. A linear dependence of the mode amplitude on transverse beam position is evident, which indicates dipole-like behaviour.

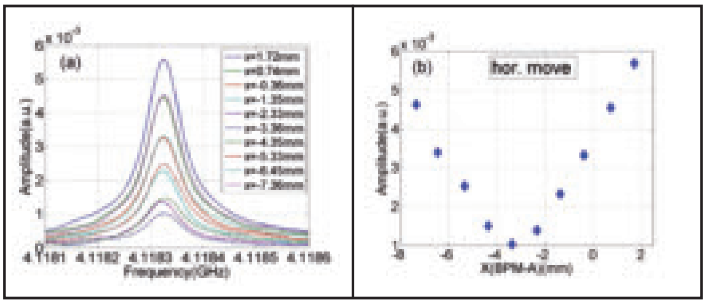


Figure 4

Amplitude of dipole beam pipe modes with transverse beam position read from BPM-A. The spectra were measured from the downstream HOM coupler of Cavity 2. The vertical position varied by ±0.24 mm during the horizontal movement.

The polarization of the two components of a dipole beam pipe mode are shown in Fig. 5(a) (4.1121 GHz) and Fig. 5(b) (4.1183 GHz). These two modes are polarized perpendicularly to each other, which is also representative of dipole-like behaviour. The symmetry of the ideal cylindrical structure is broken by the HOM couplers installed on the connecting beam pipes. This causes a splitting of the degeneracy of the eigenmodes. Inevitable manufacturing errors also cause this frequency splitting.

Localized modes in the fifth dipole passband span from 9.05 to 9.08 GHz. A linear regression method is used to correlate the amplitude of the 30 MHz spectra to the transverse beam position inside the cavity (Fig. 6).

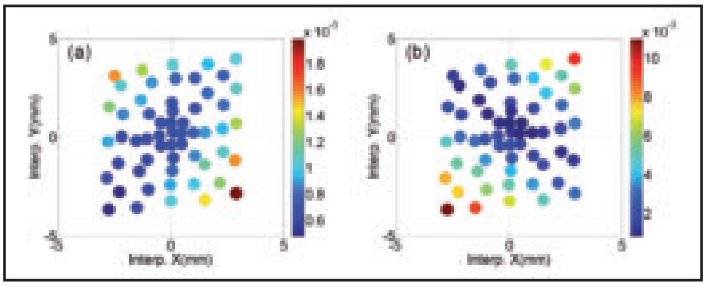


Figure 5

Amplitude of the two polarizations of a dipole beam pipe mode as a function of the transverse beam position interpolated in Cavity 2. The colour varies according to the amplitude. The signals were measured from the downstream HOM coupler of Cavity 2.

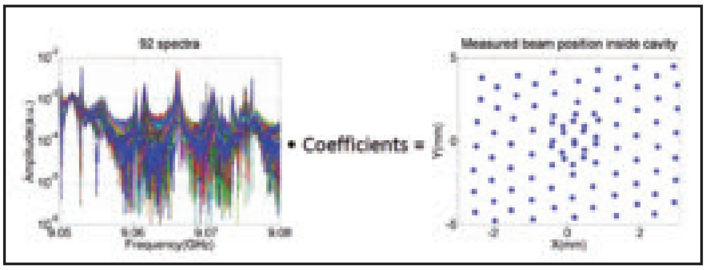


Figure 6

Correlations of HOM spectra to the transverse beam position achieved by linear regression method

Once the coefficients are determined, the transverse beam position can be predicted based on the HOM signal measured from the HOM coupler. The prediction indicates a very good consistency with the beam position measured directly from the beam position monitors (Fig. 7). The average position differences between the direct measurement and the prediction are 0.04 mm in *x* direction and 0.07 mm in *y* direction.

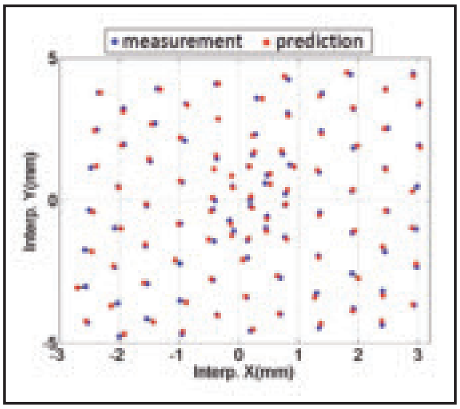


Figure 7

Measured and predicted transverse beam position inside the cavity based on the fifth dipole passband

At present, three kinds of dipole modes are considered for use as HOM-based beam diagnostics: coupled cavity modes, beam pipe modes and trapped cavity modes. The diagnostics electronics system to test all three options is currently being designed. After testing at FLASH, the performance of each option will be evaluated. Alignment accuracy is a particularly important figure of merit.

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Multilevel optimization of free-electron lasers.

Working points and particle dynamics with collective effects

The operation of free-electron lasers with high performance depends on the design of the facility and on the choice of working points. Both are based on numerical simulations of beam dynamics. Such tracking calculations of charged particles in electromagnetic fields require the equation of motion and Maxwell's equations to be solved simultaneously. The effort for high-level models that consider physical effects from first principles is large and limited by the capabilities of modern computer clusters. The resolution and precision are chosen so that a result is achieved in reasonable time. On the other hand, many fine details and effects can be omitted at the beginning or taken into account analytically. Such simple models allow fast scans to be carried out that deliver the desired results in minutes. Of course, the result of the simple model should later be checked with the full one.

Simulation and optimization

The operation of high-performance free-electron lasers (FELs) depends on the design of the facility, the requirements of users and the choice of working points. Numerical beam dynamics and FEL simulations are essential to gauge the possibilities and limitations of a machine and to predict photon properties. For a widely interested user community, very different working points in a high-dimensional parameter space have to be realized and investigated. The realization requires a fast search in parameter space, while the detailed investigation is based on tracking calculations of charged particles in electromagnetic fields that consider all important physical effects from first principles.

Some important working point parameters are the bunch charge and parameters of the multistage bunch compression system: compression ratios and energies, length–energy correlation in the bunch and dispersion in the compressor chicanes. Further parameters (for instance optics and phase advance) are related to transverse phase space. The parameter space is high dimensional and an efficient low-level model is needed to explore it. Analytic solutions are known if self-effects are negligible. Parameterized fit formulas describe the effect of beam parameters (for instance emittance and peak current) on FEL performance values, such as gain length and radiation power. The sensitivity to some parameters, such as RF phases, can be crucial.

Self-consistent tracking calculations of charged particles require the simultaneous solution of the equation of motion and of Maxwell's equations. A complete simulation from the gun to the end of the photon beamline with a general particle-in-cell (PIC) code is by far beyond today's capabilities. Therefore different methods are used for sub-problems: tracking with PIC or Poisson field solver in the gun and in linear sections, tracking with coherent synchrotron fields (CSR solver) in bunch compression chicanes, and FEL codes in undulators and for photon propagation. The effort for these high-level models is usually limited by the CPU time on modern parallel computer clusters. Therefore resolution and precision are chosen so that results are achieved in hours or days.

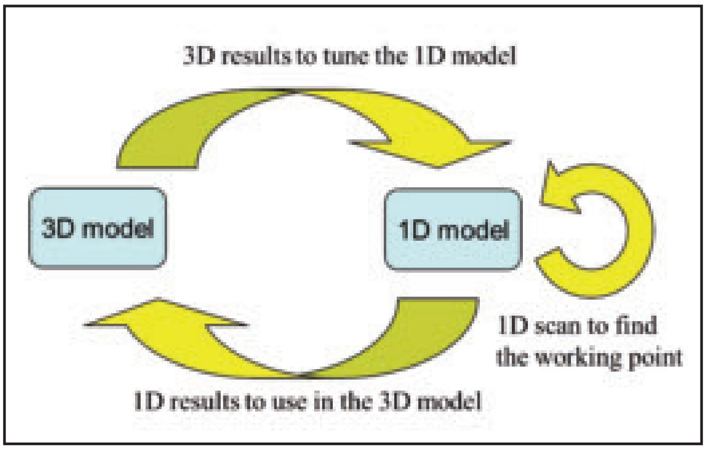

Figure 1

Iterative procedure to find the working point. We use a 3D model to tune free parameters of a simple 1D model and then employ this simple model to scan the parameter space to find the working point. The found result is checked with the 3D model and the whole procedure is repeated again if necessary.

In order to investigate the multidimensional parameter space of our FELs, we have developed a hierarchy of numerical algorithms. We start with simple analytical solutions and use 1D and 2D models for a careful scan of the parameter space. At the end, the obtained results (working points) are crosschecked with the full 3D model. The last step is also used to improve and refine the developed 1D and 2D models.

Numerical modelling of the European XFEL

FELs are usually based on the combination of a linear accelerator followed by a high-precision insertion device. The accelerated electrons travel through a spatially periodic magnetic field (the "wiggler"), which causes them to radiate light. The intensity of this

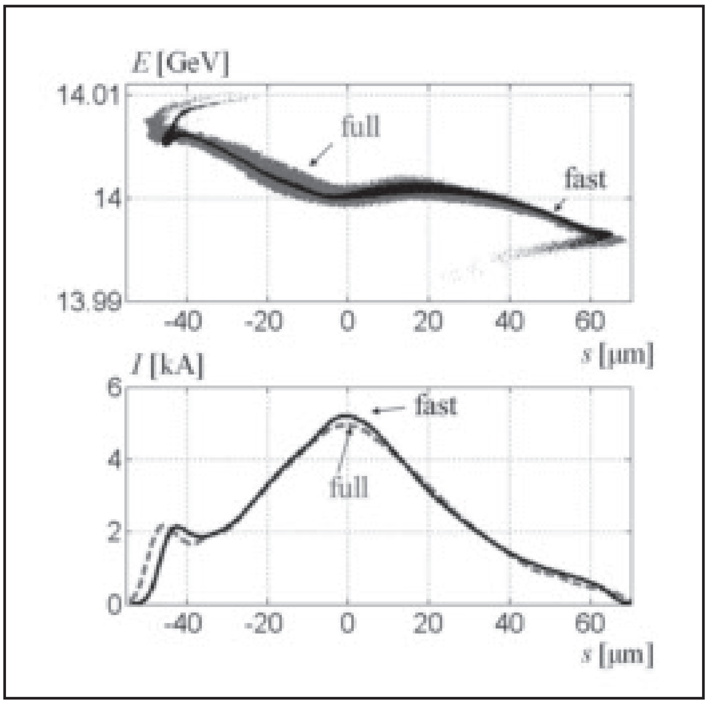

Figure 2

The longitudinal phase space and the current profile of the bunch in the European XFEL undulator section. The results of the simple (fast) model and a 3D (full) model are compared.

radiation is proportional to the square of the electron density. Thus, the beam quality critically determines the performance of the FEL. To study and optimize our design, a self-consistent beam dynamics of many charged particles interacting with each other and with their surroundings (external fields and the vacuum chamber) must be considered. The main difficulty is a large number of electrons contained in one bunch. A multiparticle system of this size cannot be efficiently simulated in full complexity even with today's parallel computers. Additional difficulties are the very different scales of different processes (for instance photon wavelength, bunch length, undulator length).

In order to achieve high phase space density, several bunch compressors are used and nonlinearities of the RF fields are corrected with a higher-harmonic RF system. Analytical estimations of RF tolerances are used to pre-optimize the parameters of the accelerator and bunch compression system. These solutions neglect collective effects that are considered in tracking calculations and further optimizations.

Important collective effects are wakefields (interaction with surroundings), space charge effects and coherent synchrotron radiation (CSR). To take into account coherent synchrotron radiation in bunch compressors, we use the code CSRtrack. This code tracks particle ensembles on arbitrarily curved trajectories. It offers different algorithms for the field calculation: from the fast "projected" 1D method to the most rigorous one, the three-dimensional integration over 3D Gaussian sub-bunch distributions. Tracking on straight trajectories is done with analytical estimations or based on the straightforward tracking code ASTRA. This program tracks particles through user-defined external fields, taking into account distortions and nonlinearities as well as space charge fields of the particle cloud.

The codes CSRtrack and ASTRA neglect the impact of the vacuum chamber. This is considered by coupling impedances (or wake functions). The wakefield code ECHO was used to extrapolate the wake of different beamline elements for ultra-short bunches. For example, the wake functions of accelerating cavities, third-harmonic modules and many other elements used in the European XFEL accelerator design are estimated with the help of this code.

For the adjustment of the RF parameters, we use an iterative procedure which starts from the analytical solution without self-interaction. The iterative scheme is robust and converges quickly to the solution. We applied this iterative algorithm in our recent studies to find the working points for the three-stage bunch compression and acceleration system in the European XFEL.

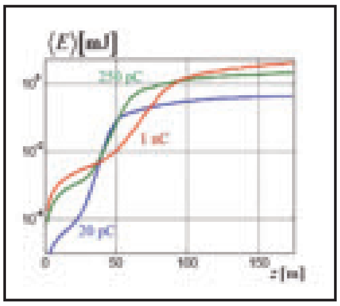

Figure 3

Mean energy in the radiation pulse for different bunch charges in the European XFEL

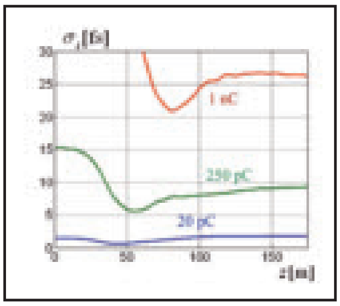

Figure 4

Radiation pulse width for different bunch charges in the European XFEL

The results of beam dynamics simulations have been used as an input for our FEL code ALICE. With the help of self-consistent simulations of the FEL process, we estimated the properties of the radiation for different charges at the radiation wavelength $\lambda = 0.1$ nm.

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Wakefields in FLASH and European XFEL.

Database development for impedance budget estimations in the European XFEL and FLASH

The European XFEL and FLASH free-electron lasers contain hundreds of sources of coupled impedances (wakefields). To have an online tool for the impedance budget estimation, we have developed a database model. The database contains information about all elements (wakefield sources) and allows the calculation of the wake potentials for arbitrary bunch shapes.

Development of the database model

Free-electron lasers require particle beams with the highest possible intensity. To preserve it, we need to study the interaction of the beam with its surrounding. This interaction is due to the wakefields excited by a bunch of charged particles moving inside the accelerator. The impedance is the Fourier transform of the wake function of the point charge.

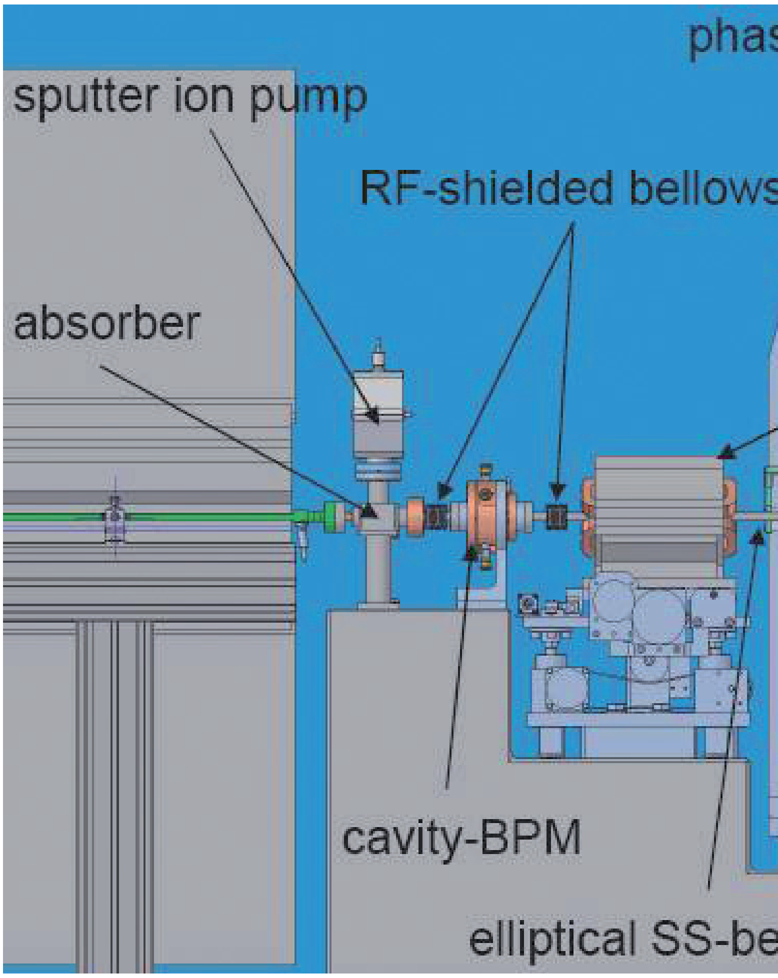
The European XFEL and FLASH contain many sources of impedances. For example, Fig. 1 shows some elements in an undulator intersection: bellows, absorber, beam position monitor, vacuum pump, round and elliptical pipes.

Usually, to estimate the impedance, we use electrodynamics codes for wake calculations. But these codes can only calculate wake potentials for Gaussian bunch shapes of relatively large rms length. In the European XFEL and in FLASH, the bunch length changes along the beamline and the real bunch shape is far from a Gaussian one. The minimal rms length of the bunch shape at the European XFEL is about 25 µm, which requires extremely high computational resources for wakefield estimations.

However, for some simple structures, the analytical models for the wake functions are known. If we know the wake function, we can calculate the wake potential for any bunch shape. For example, we have analytical solutions for the pillbox cavity, the step-out transition and the tapered collimator.

After analysis of longitudinal wakes, we have developed an analytical model that describes all cases of analytical solutions and can be used for the development of the database with wake functions for all elements.

For all components of the European XFEL and FLASH, we can fit our numerical results to the analytical models and use the analytical solutions to calculate the impedance budget. The databases for the European XFEL and FLASH contain wake functions of the point charge (Green's functions), which we can use for beam dynamics simulations. They allow us to calculate the wake potentials for arbitrary bunch shapes.



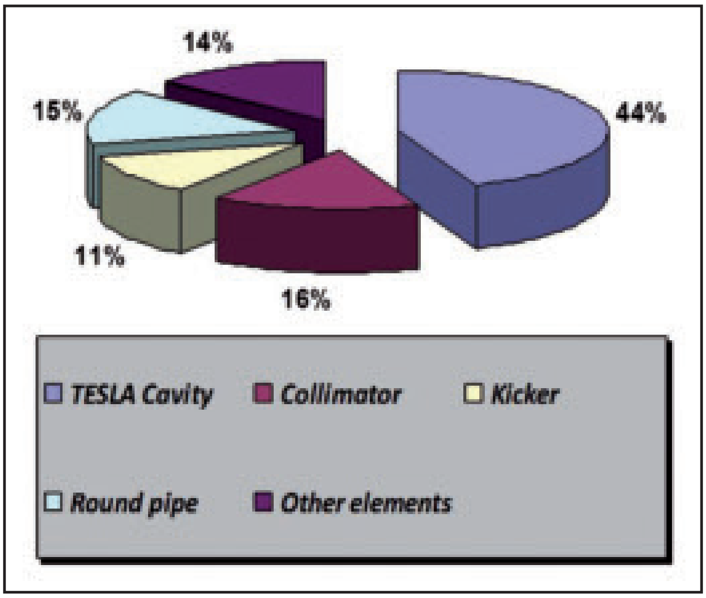


Figure 2

Impedance budget diagram

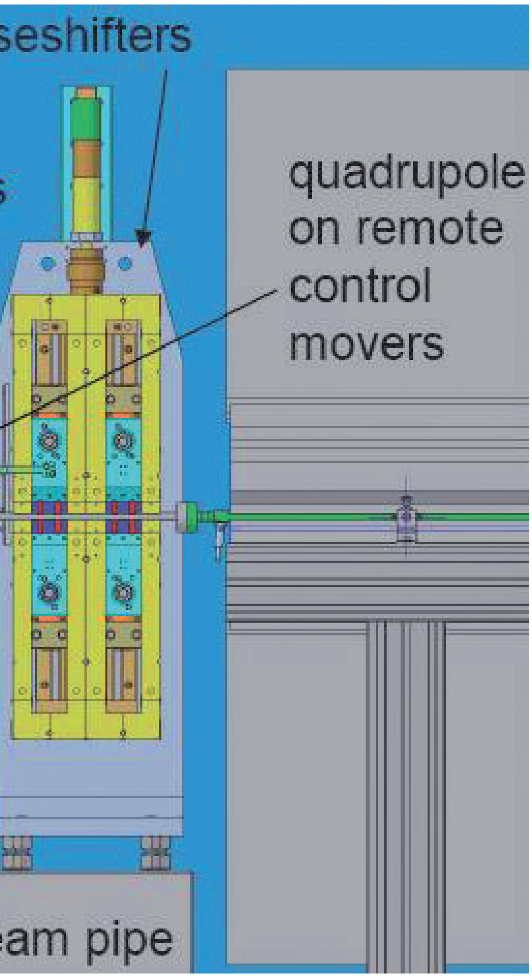


Figure 1

European XFEL undulator intersection

Description of the databases

The databases for the European XFEL and FLASH are both Microsoft ACCESS applications. With the help of different forms and reports contained in the database, it is possible to calculate the wake potential for a specific element or a group of elements with a specific bunch shape. The result can be presented graphically or as a Microsoft ACCESS report for established sections, bunch shapes or for each type of European XFEL or FLASH element.

The database for the European XFEL currently contains about 30 different types of elements such as cavities, beam position monitors, kickers, collimators, toroids, vacuum pumps, bellows and others. So far, the database for FLASH contains about 20 types of elements.

Example of impedance budget calculation

As an example, we present calculations of the impedance budget of the European XFEL section from the injector to SASE2 with a set of Gaussian bunch shapes (rms length $s = 2400$ µm, 120 µm, 25 µm). In this section, there are about 66 bellows with shielding, 114 BPMAs (a kind of beam position monitor), 808 TESLA cavities, 4 collimators, about 500 flanges, about 4 kickers, a round pipe with a length of about 456 m, 115 vacuum pumps, 8 transverse deflecting structures and other elements.

Figure 2 shows the contributions of the main elements to the impedance budget in our example. The highest contribution is due to the superconducting cavities, collimators, kickers and round pipes.

The results of the calculations can also be obtained as Microsoft ACCESS reports and as plots of the wake potentials. In the reports, the information is presented in terms of so-called loss and spread parameters and can be given for each element type, for each section and for each bunch shape used in the calculations.

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Procurement of cavities for the European XFEL.

Technology transfer for the industrialized cavity fabrication and incoming inspection of the cavity material

The procurement of superconducting RF cavities for the European XFEL is a good example of technology transfer from the scientific laboratory/research centre to the industrial production line. The main strategy was developed on the basis of 50 prototype cavities that were produced by industry and treated and RF tested at DESY. The production of serial cavities is contracted to two companies on the principle "build to print" without a performance guarantee. About 20 tonnes of high-purity niobium for superconducting cavities will be provided by DESY for the cavity fabrication. An appropriate infrastructure for the receiving inspection of many thousands of semi-finished products for the cavities is being built up at DESY. More than 30% of the cavity material has already been delivered to the cavity producers.

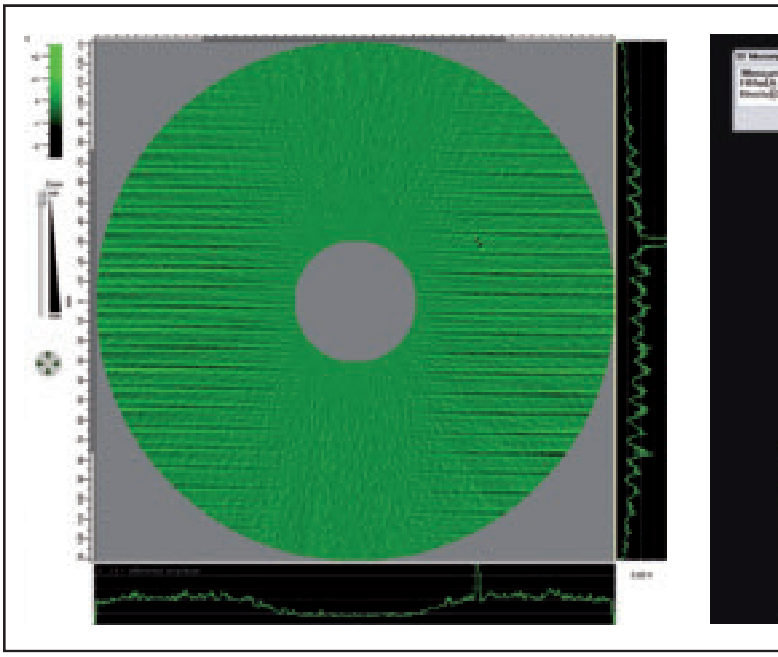
Technology transfer for cavity fabrication

The procurement of superconducting RF cavities for the European XFEL follows the well-known principles of technology transfer. The R&D for the cavities was completed during the preparation phase before starting the procurement procedure.

The preparation phase for the European XFEL cavity production includes:

- qualification of high-purity niobium vendors and potential cavity producers
- accommodation of the TESLA cavity design to the European XFEL demands
- establishing the European XFEL treatment process (in particular the final surface treatment), working out and checking the strategy of cavity arrangement for the vertical acceptance test (cavity integration into helium tank and assembly of HOM/pick-up antennas)
- defining the documentation and prompt data transfer, the qualification principles of the created infrastructure and the cavity acceptance criteria.

A detailed specification has been worked out on the basis of experience gained with ca. 50 prototype cavities. The specification pursued two main aims: to give all requirements in detail for the mechanical fabrication, treatment, assembly and transportation of the cavities; and to include DESY experience. The work was summarized for and approved by the Production Readiness Review (PRR) meeting.

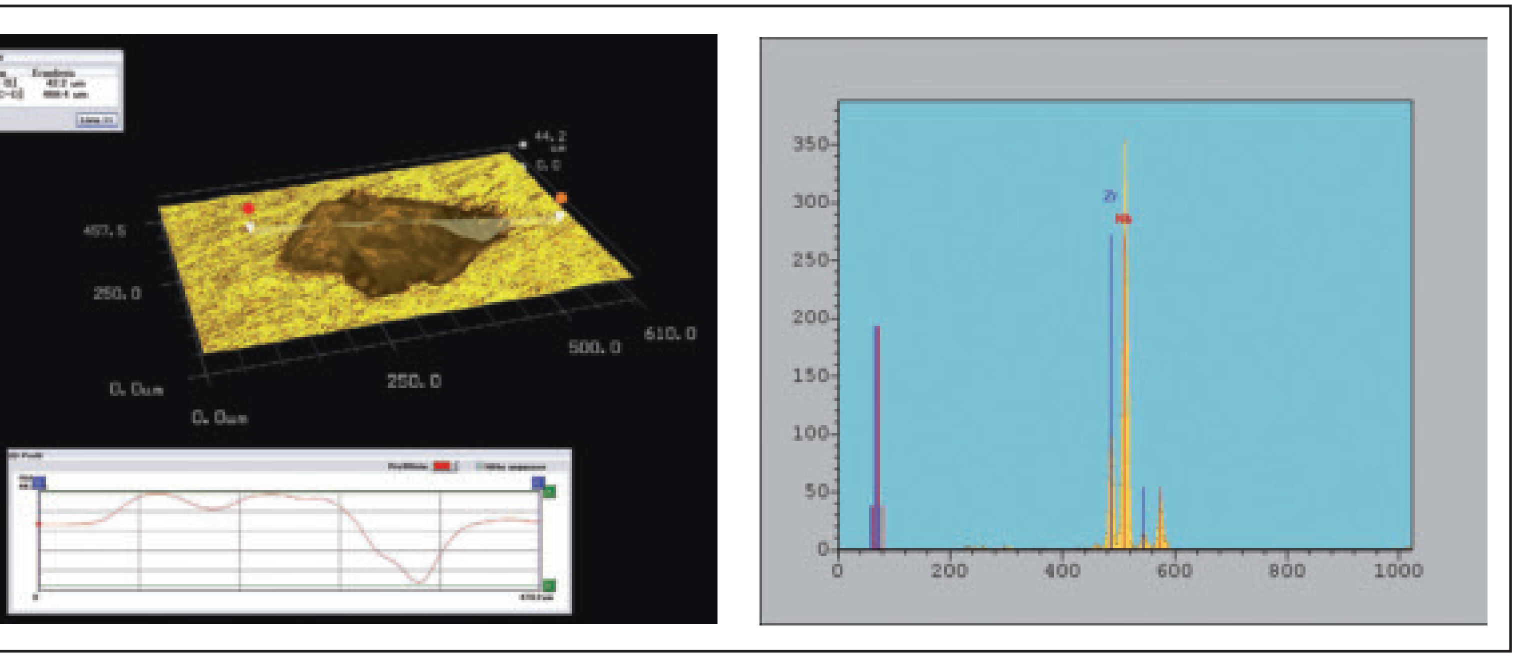


Production of 560 serial cavities is currently contracted to two companies on the principle "build to print". 240 additional cavities will be allocated in 2012. Work in 2011 was mostly dedicated to setting up a new infrastructure for serial mechanical fabrication and treatment of the cavities at the companies. Serial cavity fabrication will start in mid-2012 after qualification of the new infrastructure. The qualification will be done on the basis of reference cavities that were already produced by the companies. These cavities are being treated and RF tested at DESY. After treatment by DESY according to standard DESY processes, the reference cavities will be re-treated at the company and RF tested again at DESY to qualify the companies' infrastructure. DESY will provide the vendors with its own sophisticated equipment developed earlier (machine for cavity tuning at room temperature, equipment for RF measurement of dumb bells and end groups).

The cavity with its helium tank must be built as a component according to Pressure Equipment Directive PED/97/23/EC. The

Figure 1

Example of a foreign material inclusion (zirconium) in a Nb sheet detected by eddy current scanning (left), examined with the 3D microscope (centre) and proven by X-ray fluorescence analysis (right)



contracted “notified body” (TUEV NORD) tracks the production process. One important step of the production process qualification was the successfully implemented fabrication of test pieces containing all cavity welding connections, followed by extensive destructive examinations.

Quality inspection of semi-finished niobium material

Approximately 20 tonnes of high-purity niobium (12 different types of semi-finished products) are required for the European XFEL superconducting resonators. DESY decided to provide the cavity manufacturers with the cavity material. The work on the material for the European XFEL cavities is divided into three phases: prototyping, pre-series and series production.

The semi-finished products for the pressure-bearing subcomponents of the cavities must also be fabricated according to PED 97/23/EC. The qualification of cavity material Nb300, Nb40, NbTi and the certification of the material producers for pressure-bearing parts was done by a “notified body”. Traceability for pressure-bearing parts is guaranteed by marking and data collection. Material for the series cavities has been contracted to several companies that qualified earlier or lately for the European XFEL. Procurement includes: incoming quality control, eddy current scanning of the sheets, testing for required parameters (residual resistance ratio (RRR), interstitial impurity analysis, metallic impurities analysis, metallography, tensile test, hardness (HV), dimensional check and surface roughness), documentation using the DESY Engineering Data Management System (EDMS), definition of numbering system and marking, delivery to the companies. An appropriate infrastructure and logistics for guidance through more than 20 000 semi-finished products was created at DESY and the details of the workflow were worked out.

The quality of the high-purity niobium sheets from which the cavity half-cells are made is especially critical for the cavity performance. Approximately 5000 sheets were scanned up to now using eddy current devices. Some of the sheets exhibit an increased eddy current signal, as shown in Fig. 1. Subsequent detailed analysis allowed the definition of the following defect categories: foreign material inclusions (tantalum, iron and nickel) and topographical defects (scratches, holes and pits, marks and lamellas). Information about deviations from the specification is immediately given to the companies. Close joint work with the companies significantly contributes to the high quality of the material. About 30% of the material for the cavity production has already been handed out to the cavity manufacturers.

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Technical interlock for the AMTF.

Electronics development for technical protection of the power couplers and cavities in the AMTF

More than 800 cavities and 100 cryomodules for the European XFEL will be tested in the Accelerator Module Test Facility (AMTF). The goal is to measure the performance limits of the accelerating RF cavities and their accessories. At the same time, the RF components must be protected against technical degradation during the test. A technical interlock was developed to monitor miscellaneous signals collected at the RF components and the test system itself.

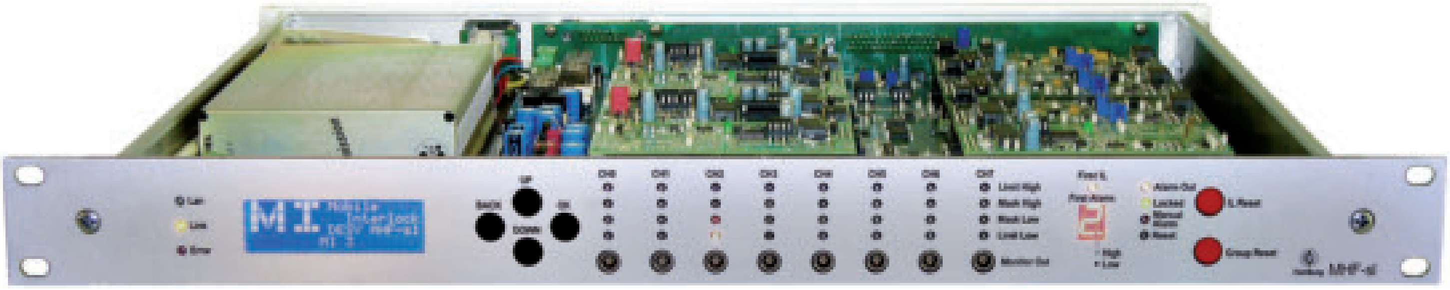

Figure 1

Technical interlock device for the AMTF

Technical interlock electronics was developed for the performance test of more than 800 RF cavities and 100 cryomodules in the AMTF (Fig. 1). During the first performance test, the RF components are also RF conditioned. RF conditioning is a controlled desorption of absorbed gases by accelerated ions and electrons inside the components. The interlock protects the various RF components like power couplers and cavities inside the cryomodule from overstraining during the first power rise. It provides the possibility to set thresholds for the signals at which the RF power will be limited or even switched off.

In particular, the technical interlock monitors the following signals at the test environment:

- cooling conditions, like helium level and pressure
- vacuum conditions in the RF power coupler and cavity

and at the RF components:

- light in the waveguide and coaxial coupler parts
- charged particles in the coupler vacuum
- temperatures of the ceramic power coupler windows.

The configuration for the module test stand can be seen in Fig. 2.

For every channel, the electronics provides an adjustable amplifier, a frequency filter and an adjustable upper and lower threshold. The architecture is modular; three exchangeable electronic modules are available:

- analogue in card (for helium level and pressure, vacuum and light)
- PT100/PT1000 card (temperature)
- e- card (charged particles).

All functions and settings are remote-controlled, but all information is also available at the device itself.

In 2011, the firmware was completed and new functions have been implemented. If the threshold of one of the signals is exceeded during operation, the system interrupts the RF power. In addition, the components of the interlock system itself are monitored and included in the safety concept. If, for example, one component loses communication with the microcontroller or is not able to keep its settings, the interlock interrupts the RF power. All parameters are constantly checked inside the unit and, in addition, by the external DOOCS server (Fig. 3). This guarantees that each unit works self-sustainingly even after an electrical power outage, for example, or without network connection.

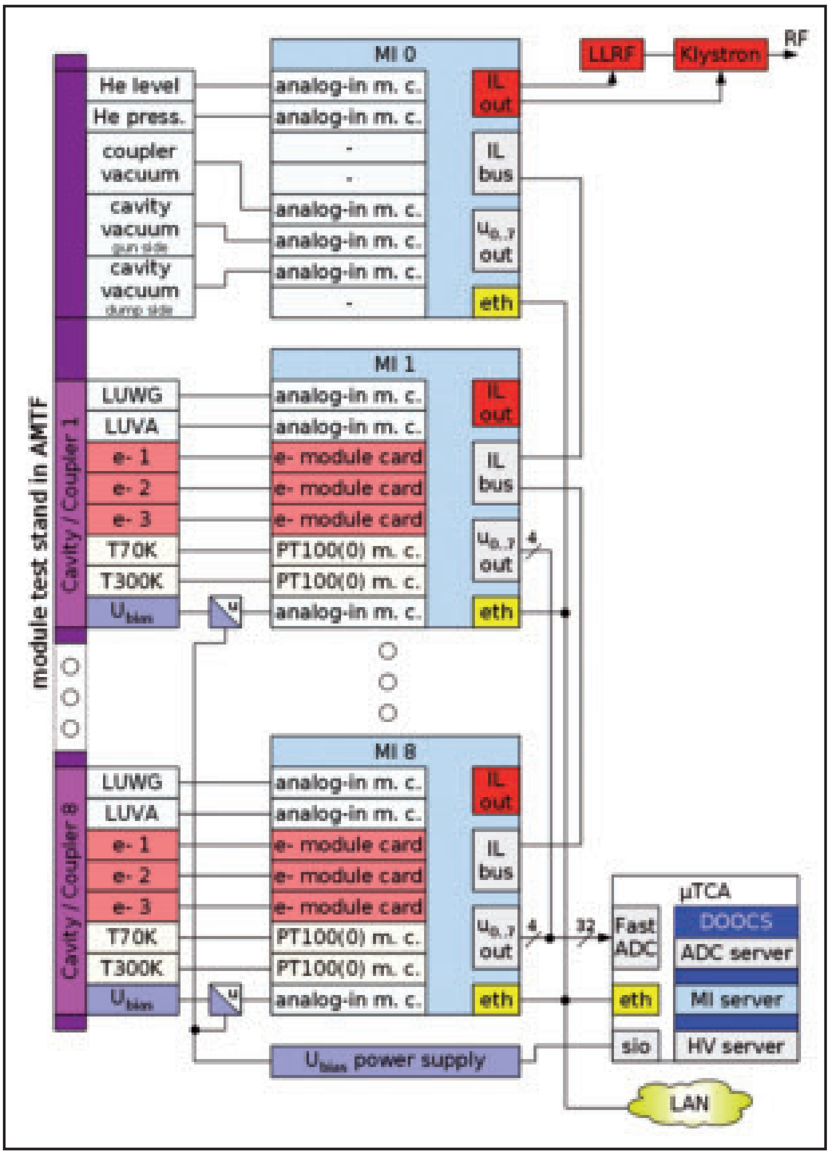

Figure 2

Block diagram of the interlock configuration for a module test stand in the AMTF

Furthermore, a new external DOOCS server for surveillance and parameterization of the interlock systems is being developed. Special attention was given to the authentication of the server inside each unit. The server denies control of a device if it is already under control of another server. Another feature which is very helpful in the test environment (where the sensors are often assembled and disassembled) is the automatic diagnosis of the sensor supply. In case of a short on a sensor, for example, the server can diagnose it, switch off the generating channel and will not allow RF operation until the problem is solved.

To allow an easy “overall” interlock test after assembly of a new module or cavity and before starting the RF conditioning, the system includes a sensor check for every channel. When the sensor check is started, the system supplies a defined signal as close as possible to the sensor (e.g. a light source will be switched on in front of the light detector or a current will be applied close to the antenna for charged particles). The server then compares the channel signals with the expected signals and shows the result on a user panel. This new interlock system has already been successfully tested and used in the existing Cryo Module Test Bench (CMTB).

The development of this interlock system is a big step towards a new European XFEL interlock. Especially the remote control of all parameters and the automatic self-test of the sensors are major requirements for the operation of multiple systems in an accelerator tunnel without permanent access. The new European XFEL interlock system is under development and will include many more channels per volume.

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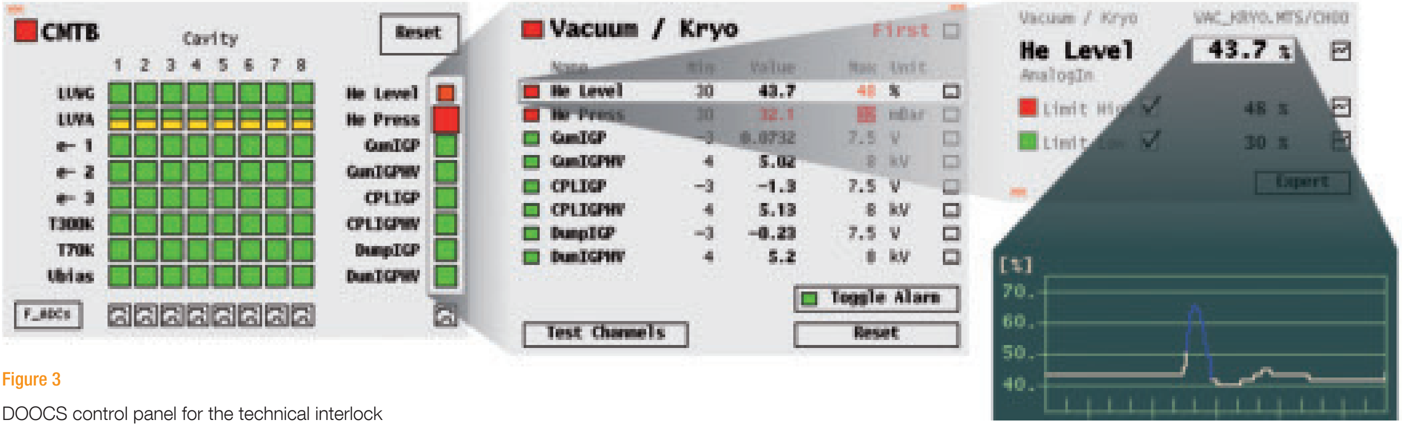

	1	2	3	4	5	6	7	8
LUWG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
LUVA	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
e- 1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
e- 2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
e- 3	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
T300K	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
T70K	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Ubias	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

He Level	🟥
He Press	🟥
GunIGP	🟩
GunIGPHV	🟩
CPLIGP	🟩
CPLIGPHV	🟩
DumpIGP	🟩
DumIGPHV	🟩

Vacuum / Kryo

	Name	Min	Value	Max	Unit	
🟥	He Level	30	43.7	48	%	☐
🟥	He Press	30	32.1	[illegible]	mBar	☐
🟩	GunIGP	-3	0.0732	7.5	V	☐
🟩	GunIGPHV	4	5.02	8	kV	☐
🟩	CPLIGP	-3	-1.3	7.5	V	☐
🟩	CPLIGPHV	4	5.13	8	kV	☐
🟩	DumpIGP	-3	-0.23	7.5	V	☐
🟩	DumIGPHV	4	5.2	8	kV	☐

Vacuum / Kryo VAC_KRYO.MTS/CH00

He Level 43.7 %

AnalogIn

🟥 Limit High ✓ 48 %

🟩 Limit Low ✓ 30 %

Figure 3

DOOCS control panel for the technical interlock

European XFEL master model.

Organizing the large-scale collaborative design process for the European XFEL

The European XFEL X-ray laser is a large and complex facility currently under construction in Hamburg. It consists of millions of parts and components, which are contributed by numerous laboratories from a dozen different countries. How can we make sure that all these elements fit together? The answer is a sophisticated collaborative engineering process, which coordinates and integrates the design contributions from the project's many work packages.

International design collaboration

The European XFEL project structure implements more than 50 work packages, which are responsible for providing the different technical subsystems, establishing all technical infrastructures and performing general tasks. Many work packages have their own teams of designers, who develop all the parts and subsystems required in the accelerator project. They create design models of the various accelerator components, such as sources, accelerating modules, magnets, beam dumps, diagnostics, cryogenics and the vacuum system. In addition, they produce architectural models of all the tunnels, shafts and buildings, as well as system models of the various infrastructures – electrical, water, ventilation, safety, transportation and survey.

The design teams strive to come up with optimum solutions for their components, while at the same time having to make sure that their solutions stay compatible with the developments in all the other work packages. A permanent process of design integration, clash checks and negotiation ensures that the evolving designs are as well balanced as possible towards the many different needs and interests.

The integration process is fostered by a central design integration team, which receives the contributions from the work packages. The integration team puts the different subsystem and component models together into so-called master models. Master models show fully equipped tunnel sections, shafts or buildings. They are used for design integration and optimization. The integration team checks the master models for completeness and ensures that the different components fit properly into their interfaces and do not overlap. The emerging master models are negotiated until they converge into a complete, consistent and clash-free model of the entire facility that is acceptable to all participants.

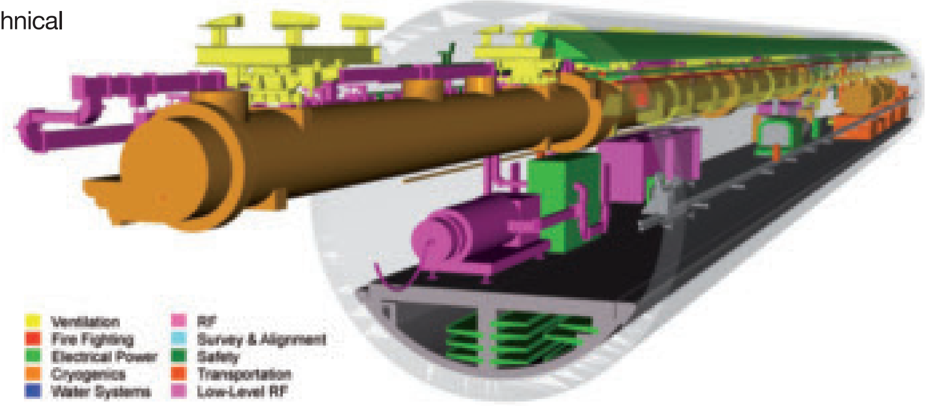

Figure 1

Master model of a 52-m-long tunnel segment that has been created from contributions of 13 different design teams

The integration team manages more than 160 master models of different tunnel sections and building complexes, which integrate more than 15 technical systems. They have been combined into a model of the complete European XFEL facility that assembles more than 200 000 parts – and allows the project team to even now take a virtual tour of the European XFEL from the injector to the experiments.

One of the major benefits of the design process is that design conflicts at resolved at an early stage in the project. These early clash checks lead to significant cost savings, as they prevent conflicts from reaching the construction site, where they would cause unbudgeted changes and delays in the project schedule.

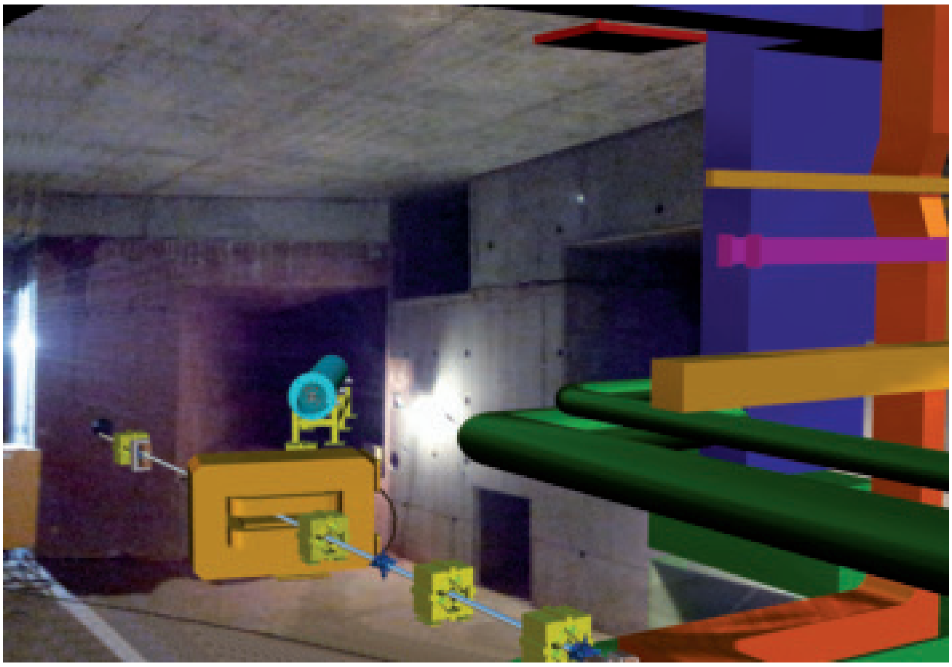

Figure 3

Completed injector building and planned accelerator fit nicely.

Everybody at their own pace

Construction of the European XFEL facility will last about five years. First, the tunnels, shafts and buildings are created. Then the technical infrastructures are established, before the accelerator components are finally installed and put into operation. This long period implies that the design and fabrication activities of the various subsystems do not all happen at the same time. On the contrary – the design of some systems must be finalized already in very early project stages, when the details for other systems that are produced later may not yet be fixed. And any system will of course be optimized and thus undergo design changes for as long as possible. But how can the master models be created when all the subsystem models arrive at very different times?

Figure 2

Completed accelerator tunnel and planned installations fit nicely.

The key concept for disentangling the various design contributions is the use of so-called placeholder models. Placeholders describe the maximum space required by a component. This is usually the component envelope plus additional room for e.g. tolerances, tooling and fixtures for transportation. Placeholders contain all the information necessary for design integration, but do not require unnecessary details. Hence design teams only need to announce their space requirements early in the project. They are then free to proceed with the detailed design according to their schedule. The detailed component models only need to be checked against the placeholders. As long as they do not protrude from the placeholders, they are safe and no further negotiation with other groups is needed. In this way, placeholders decouple detailed design activities from the overall facility layout and planning processes.

Vision sharing

The omnipresence of design models has another important effect on the overall effectiveness of collaboration: vision sharing. Thanks to the master models, all members of the project team share the same picture of the facility and the project. They are thus able to better target their individual contributions to the context and performance of the overall facility, and to discover needs and opportunities for linking with other work packages.

In addition, visualization enhances communication, as it enables the team to address and describe specific parts of the facility more accurately and easily. As an overall result, visualization leads to better decision making.

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LLRF and laser synchronization for REGAE.

First radio frequency operation and beam at REGAE

The Relativistic Electron Gun for Atomic Exploration (REGAE) is a new accelerator facility at DESY that will generate very low-charge (1 pC) electron bunches of a few femtoseconds duration for electron diffraction pump-probe experiments. The arrival time jitter between the electron bunch and the pump-probe laser must be below 10 fs (10^{-15} s). To meet these requirements, the 3 GHz radio frequency (RF) field in the two normal-conducting S-band structures must be stabilized to a level of 0.01% in amplitude and 0.01 degrees in phase, while the laser has to be synchronized to the RF in a sub-10 fs range. For the low-level RF (LLRF) controls and the laser synchronization, electronics in the new MicroTCA.4 crate standard is used.

The RF system at REGAE

The RF system at REGAE (Fig. 1) consists of two normal-conducting S-band structures operating at 3 GHz, the RF gun and the buncher cavity. The electron bunches are generated by impinging ultrashort laser pulses (270 nm) onto a photocathode. They are then accelerated within the 1 ½-cell RF gun to an energy of 5 MeV. The 4-cell buncher cavity after the RF gun induces an energy chirp by accelerating the electron bunch 90° off-crest. In the following drift section, the bunch length is then compressed below 10 fs.

The two structures are powered by a single klystron. Through the waveguide distribution system, 3/4 of the power is sent to the RF gun, while 1/4 goes to the buncher. The phase difference of 90° is achieved by a remotely controllable waveguide phase shifter. The RF system at REGAE operates in a pulsed mode with a repetition rate of 50 Hz and an RF pulse length of 6 µs. Waveguide couplers and probe pickups are installed to monitor the RF power and to control the electrical field in both structures.

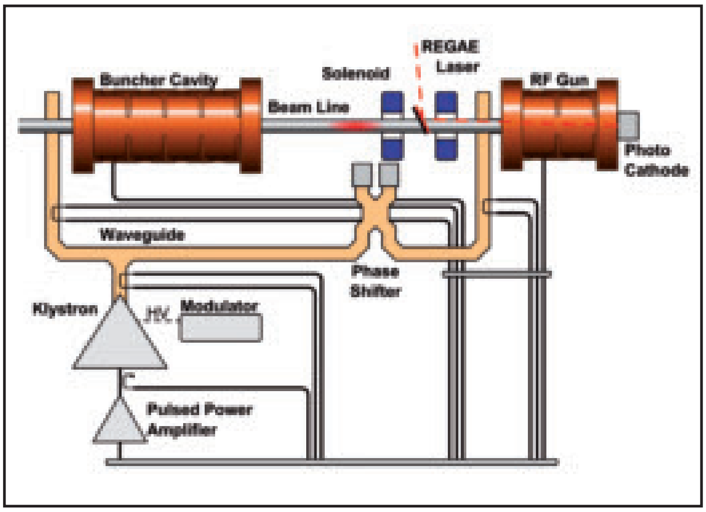

Figure 1

The RF system at REGAE consists of two normal-conducting S-band structures operating at 3 GHz, the RF gun (110 MV/m) and the buncher cavity (20 MV/m), powered by one klystron.

The low-level RF system

To control the electric field of the two structures, the real and imaginary parts of the field are measured using an intermediate-frequency sampling scheme. As shown in Fig. 2, the RF signal at 3 GHz is down-converted in an RF mixer with a local oscillator (LO) at 3.025 GHz to an intermediate frequency (IF) of 25 MHz and sampled by an ADC with a fixed sampling rate (CLK) of 125 MHz. The fixed ratio between IF and CLK allows for the use of a simple digital filter for the IQ detection algorithm.

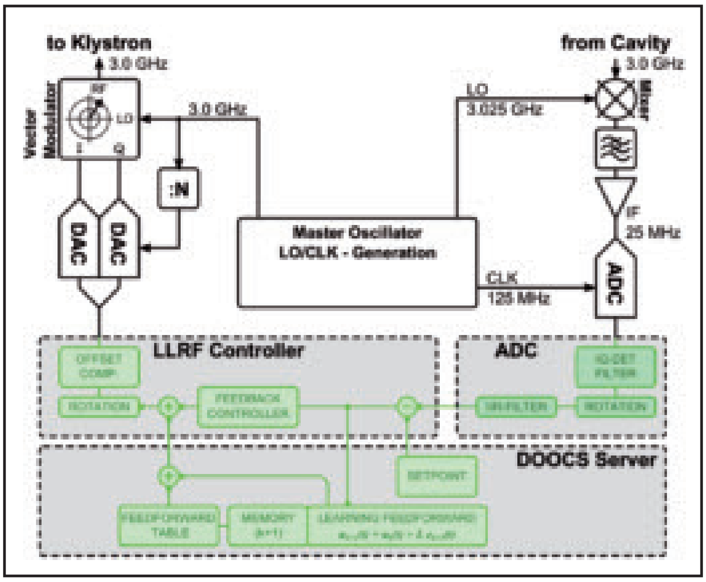

Figure 2

The LLRF system at REGAE. The digital field detection and data acquisition are implemented on the ADC board. The feedback controller and DAC driver are located at the controller board. Learning feed-forward and the set-point are calculated by the server, located on the crate CPU.

In the FPGA-based LLRF controller (Xilinx Virtex 5), the detected cavity field is compared to a given set-point. The error signal is used to generate the appropriate feed-forward signal through a model-based iterative-learning control algorithm and a feedback signal through an intra-pulse proportional-feedback controller.

The feed-forward and feedback signals are added and sent through two DACs, using an RF vector modulator and a pulse power amplifier to drive the klystron. The LLRF system has to detect 10 signals (Fig. 1) with high precision.

For the operation of the LLRF and the laser synchronization system (LSynch), the following synchronous and phase-stable frequencies are generated in the master oscillator (MO): 1 GHz for the timing system, 3 GHz for the LLRF and LSynch, and 83 MHz for the LSynch (optional). The LO at 3.025 GHz and CLK at 125 MHz for the field detection are generated in the LO generation crate from the 3 GHz of the MO.

The hardware platform for the LLRF and the LSynch is based on the new industry standard MicroTCA.4 recently released by the PICMG (PCI Industrial Computer Manufacturers Group). It is planned to be used for the European XFEL accelerator controls and has been demonstrated at FLASH.

Laser synchronization at REGAE

A Ti:Sapphire laser system is used to generate the electrons in the RF gun by frequency-tripling the 810 nm to 270 nm and to carry out the electron diffraction pump-probe experiments at the end of the beamline. The synchronization system locks the laser repetition rate to the RF master oscillator. This is accomplished by extracting the 36th harmonic of the 83.3 MHz laser pulses with a photodiode and a narrow bandpass filter, centred at 3 GHz. The extracted phase is compared with the phase of the 3 GHz from the MO and applied in a feedback loop, which acts on the laser repetition rate using a piezoelectric actuator. In the first run of REGAE, the feedback was accomplished by a simple analogue controller.

First results of RF and laser operation

Because of the short RF pulses and the high bandwidth of the normal-conducting structures compared to the superconducting cavities at FLASH and the European XFEL, a sampling rate of 125 MSPS is used, which allows for the measurement of the high dynamic range of the system and, depending on the delay in the control loop, the implementation of a fast intra-pulse feedback. The data readout was limited to only six 32 Bit channels (two times 16 Bit for real and imaginary part) due to the data rate of the external memory on the ADC board. To provide all signals to the control system, a multiplexing scheme was implemented, which allows to read out every second pulse. This scheme is used for the forward and reflected signals and the 3 GHz reference. Because of the bandwidth limitations of the low-latency link between the ADC and controller board, the learning feed-forward and fast feedback could not yet be applied. Figure 3 shows the RF signals from the first operation of the REGAE LLRF system in feed-forward mode only. The RF gun is well tuned and shows the expected behaviour. The tuning depends on the temperature of the cooling water.

The resolution of the field detection is 0.035% in amplitude and 0.02 degrees in phase for the full analog detector bandwidth of 80 MHz. It is measured by tracking the 3 GHz reference from the MO in parallel. Since the cavity bandwidth is 300 kHz only, this results in a resolution of 0.007% in amplitude and 0.004 degrees in phase at 3 GHz, the effective bandwidth of the system in feedback mode with a feedback gain of 10. This limits the field stability of the cavity to approximately 4 fs at 3 GHz.

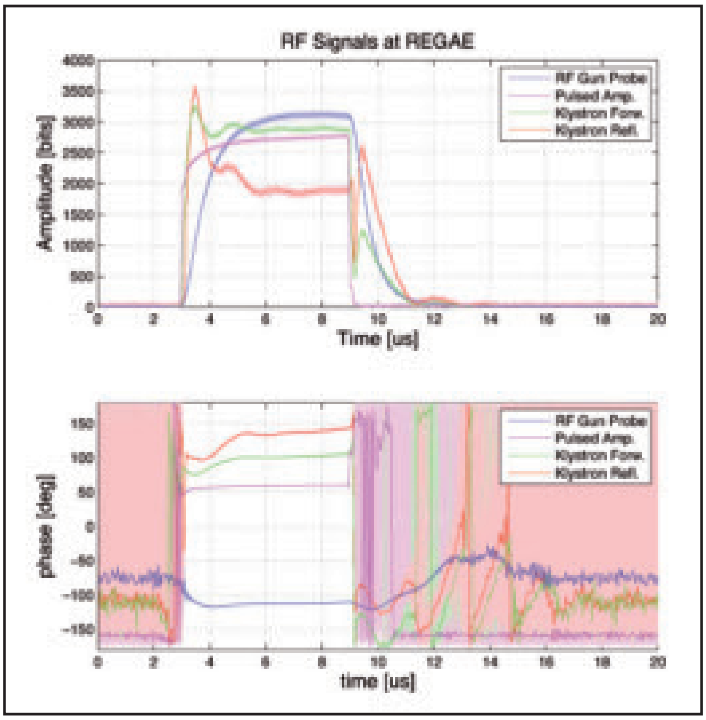

Figure 3

Amplitude (top) and phase (bottom) of the RF gun probe, pulse power amplifier output, klystron forward and reflected. The pulse-to-pulse fluctuation of the RF gun probe (blue), measured over 100 pulses in open loop (no control of the field), is 0.3% in amplitude and 0.07 degrees in phase.

Outlook and future plans

The next step is to establish ultrastable RF and laser operation through careful signal calibration and tuning. To solve the limited data storage rate in the ADC memory and the limited bandwidth of the digital link between controller and ADC, the data rate will be decimated to 62.5 MSPS. Then twelve 32 Bit channels can be stored in the ADC memory and the transfer of two 20 Bit signals to the controller is feasible. Appropriate stabilization is achieved by applying the fast feedback and learning feed-forward algorithm.

A digital feedback for locking the laser has already been tested. The feedback is based on an IF-sampling scheme using the same hardware as for the LLRF. The advantage of the scheme is the cancellation of LO drifts and a much higher flexibility in the laser feedback algorithm (e.g. notch filter). Further developments include the integration of beam diagnostic signals (Faraday cup, dark-current monitor) processed in the MicroTCA.4 crate and the installation of a drift calibration system to compensate long-term drifts of the down-converter and the RF cables.

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The dark-current monitor at PITZ and REGAE.

A new non-destructive monitor to measure dark current and bunch charge

A non-destructive resonator has been developed to measure the dark current and the bunch charge at the PITZ photoinjector test facility at DESY, Zeuthen Site. The monitor with electronics provides a measurement range between 100 nA and 600 µA. The beam charge can be measured as well with a lower limit of 10 pC, limited by the noise of adjacent devices. This monitor has also been installed at the Relativistic Electron Gun for Atomic Exploration (REGAE), where bunch charges between 20 fC and several pC are observed. The measured resolution is 4 fC; the charge range is between 10 fC up to several nC.

Dark current (DC) is produced by field emission in linear accelerators. It generates a radiation background in the tunnel which can damage electronics and activate components. Kickers, doglegs and collimators are used to remove the dark current. To measure the efficiency of the reduction, beam loss monitors (indirect) and destructive Faraday cups (FC) are used. To improve this measurement and provide the required data in a non-destructive manner, a dark-current monitor (DaMon) was developed and constructed by the DESY Machine Diagnostics and Instrumentation (MDI) group. This monitor consists of a resonator for which the frequency of the monopole mode is a harmonic of the acceleration frequency. The fields induced from successive weakly charged dark-current bunches therefore add up to a measurable field level.

A few monitors were produced with a resonance frequency of 1299.3±0.1 MHz of the first monopole mode without tuners. The bandwidth is 6.7 MHz, therefore the resonance frequency is sufficiently close to the acceleration frequency of 1.3 GHz. Each monitor provides two similar outputs. Prototype electronics has been produced with two branches: one is used to detect the DC and the other the charge. Each branch includes a logarithmic detector which provides a large dynamic range. The DC electronics has a higher sensitivity due to an additional amplifier; in addition this branch must be protected with a circulator and a limiter. The charge branch is meant to be used with attenuators. Both branches are calibrated with continuous-wave (CW) pulses of the first monopole resonance frequency of the DaMon.

One DaMon was installed at the PITZ photoinjector test facility at DESY, Zeuthen Site. It is situated behind the photocathode gun and before the second acceleration cavity (booster). The prototype electronics is read out with standard ADCs. Therefore the results are already available in the control system at PITZ. Figure 1 shows two pulses of DC. The long DC pulse of 20 µA amplitude is produced by the gun. The lowest limit of the measurement is 100 nA, limited by noise. The DC pulse of about 460 µA amplitude is produced by the booster. In this case the DaMon measures field-emitted electrons travelling in the backward direction. The DC level of the booster is much higher than that of the gun. This unexpectedly high DC is still below the saturation limit of the electronics at 600 µA.

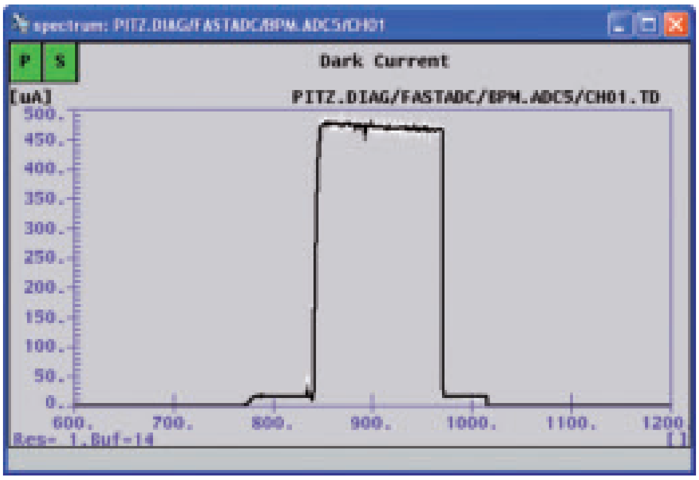

Figure 1

Dark current of gun and booster at PITZ in µA as a function of time in µs. The lower-amplitude component is the dark current from the gun; the shorter higher-amplitude component is produced by the booster. This diagram is already available in the PITZ control system.

A measurement of the beam charge is shown in Fig. 2. The charge is about 225 pC. The baseline shows a noise level of 10 pC which is generated by adjacent devices. The upper limit of the charge measurement is 10 nC, limited by the saturation of the charge electronics. PITZ is operated between several pC up to a few nC, therefore the provided charge range from the DaMon is sufficient.

The DaMon was also installed at the Relativistic Electron Gun for Atomic Exploration (REGAE). As the acceleration frequency of about 3 GHz is not a harmonic of the monopole mode, DC cannot be measured with this device. The machine is intended to produce low-charge electron beams, therefore the DaMon is used to detect the bunch current with high resolution in a non-destructive manner.

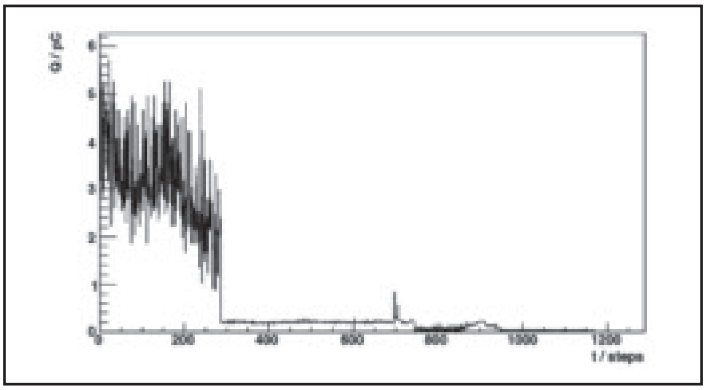

Figure 3

Measured electron beam charge at REGAE as a function of time at different machine settings taken with the DC electronics

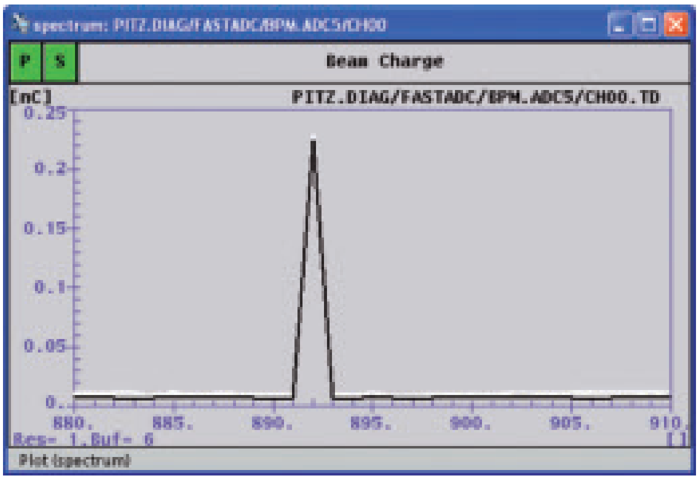

Figure 2

Beam charge at PITZ as a function of time in µs. This diagram is already available in the PITZ control system.

Both electronics branches are used to measure the bunch charge. The data are taken with an oscilloscope. The charge values measured by the charge electronics are in agreement with Faraday Cup results. The charge provided by the DC electronics had to be recalibrated with the results from the charge electronics, because the calibration with the CW pulse and a longer time constant results in higher amplitude compared to a single pulse from a beam.

Figure 3 shows the electron beam charge measurement with the DC electronics at different machine settings. Two different machine settings are visible: high charges of about 3 pC and lower charges of about 200 fC. The differences of the values taken with both electronics branches at about 3 pC beam charge are shown in Fig. 4. The resolution of the complete system is indicated by the Gaussian fit sigma of 140 fC.

The differences of the beam charge measurements at about 200 fC taken with both electronics branches are shown in Fig. 5. The offset of 28 fC is due to a non-perfect calibration. The shown standard deviation corresponds to the resolution of the system.

The resolution is lower than that with higher charge because of the logarithmic detector. The resolution is reduced to 4 fC taking into account the influence of the 8-bit ADC of the oscilloscope. The result is better than that observed at PITZ where the same electronics is used. This proves that the noise observed at PITZ is caused by adjacent devices.

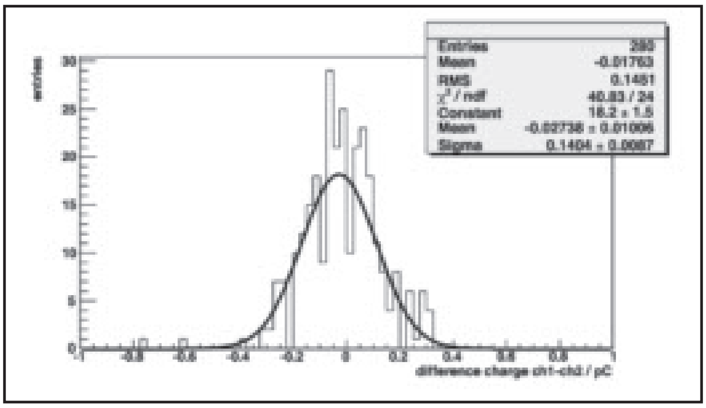

Figure 4

Histogram of the differences of the measured beam charges of both electronics branches at REGAE at about 3 pC mean value and a Gaussian fit

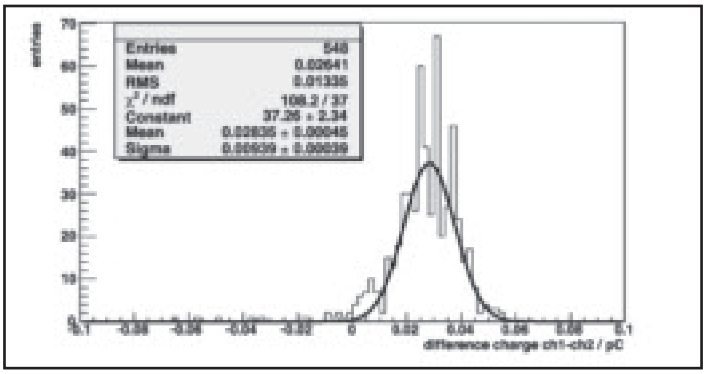

Figure 5

Histogram of the differences of the measured beam charges of both electronics branches at REGAE at about 200 fC mean value and a Gaussian fit

The range of expected bunch charges at REGAE is between 100 fC and 50 pC. The DC electronics saturate above 50 pC; the charge electronics can be used up to several nC. The provided resolution and dynamic range of the DaMon system therefore fulfils the requirements at REGAE.

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DACHS.

Access controls for DESY

In 2008, the DESY accelerator division started operating the DESY Access Handling System (DACHS). Since then, DACHS has evolved into a universal system for access control that is adapted to DESY's special requirements. It is in use at both DESY sites, Hamburg and Zeuthen, and supports the operation of accelerators, experiments, laboratories and other areas regarding safety aspects. By now, DACHS is used by several thousand employees and guests. The system controls access to more than 150 areas with very different requirements and has contributed to a new, more transparent security culture at DESY.

Goals and history

DACHS was developed to replace the old access control system HACSY at the 6.4-kilometre-long HERA accelerator. The new system checks all necessary requirements for access, such as work orders, instructions or the possession of an official dosimeter, on a daily basis. It thus supports the implementation of compulsory demands, like the German radiation protection regulation.

DACHS was launched in summer 2008 and is now used throughout DESY to support the operation of accelerators, experiments, laboratories and other areas regarding safety aspects. After equipment of the accelerators, gradually all experimental areas of PETRA III, which was reconstructed in 2009, were fitted with the new access control system, as well as many control huts, halls, chemical and laser labs and workshops. The design of isolated solutions could be avoided.

Range of applications, organization and infrastructure

The DACHS system is more than just a conventional access control system. It is tailored to DESY's particular needs and tightly linked to other systems, especially to those responsible for personnel safety within accelerators and experimental areas. Its tasks are the authentication of persons and access authorization. It generates archives of the accesses to areas that are relevant for the radiation protection division and provides evacuation lists in cases of emergency, e.g. for the underground accelerator HERA. The new concept for the area search done by a single person is a novelty, which was approved by the German Technical Control Board. The skilled coupling to the personnel interlock system of the experimental areas provides a safe and user-friendly area search by authorized users. Being used about 10 000 times per month, this solution is now one of the main applications of the DACHS system. Meanwhile, it is also implemented at the new accelerator REGAE.

The administration of access authorizations, work orders and instructions is organized in a decentralized way. The permissions to read or add data are based on roles, such as group leader, instructor or being one of the responsible persons for an area. A special database application was developed. It is used by more than 100 different persons who read and add data such as authorization rights or instructions. The application is integrated into the DESY IT structure to simplify the data exchange with existing databases and to avoid parallel developments. It is linked to the databases for personnel data, IT accounts and a special database dealing with dosimeters, and receives a relevant part of its data from a gateway for the photon users. The technical basis for the stable cooperation is the central Oracle database system of the computing centre. The variety of areas generates about 130 access rights respectively work orders. The necessary requirements are represented by more than 100 different instructions. Up to now, about 20 000 database entries are registered. A commercial system was implemented for the technical realization on site. It consists of hardware such as terminals, controllers, cards supplied with a near-field RFID chip and a software system.

Extensions in 2011

In the course of 2011, the new accelerator REGAE, two large halls, many control huts and laboratories of the PETRA III hall, as well as the incoming goods department and its customs area were equipped with DACHS. At the lock and key service where most cards are created and handed out, the first so-called Info Terminal was installed to provide users with information about their access rights. Evacuation lists for the clean room and

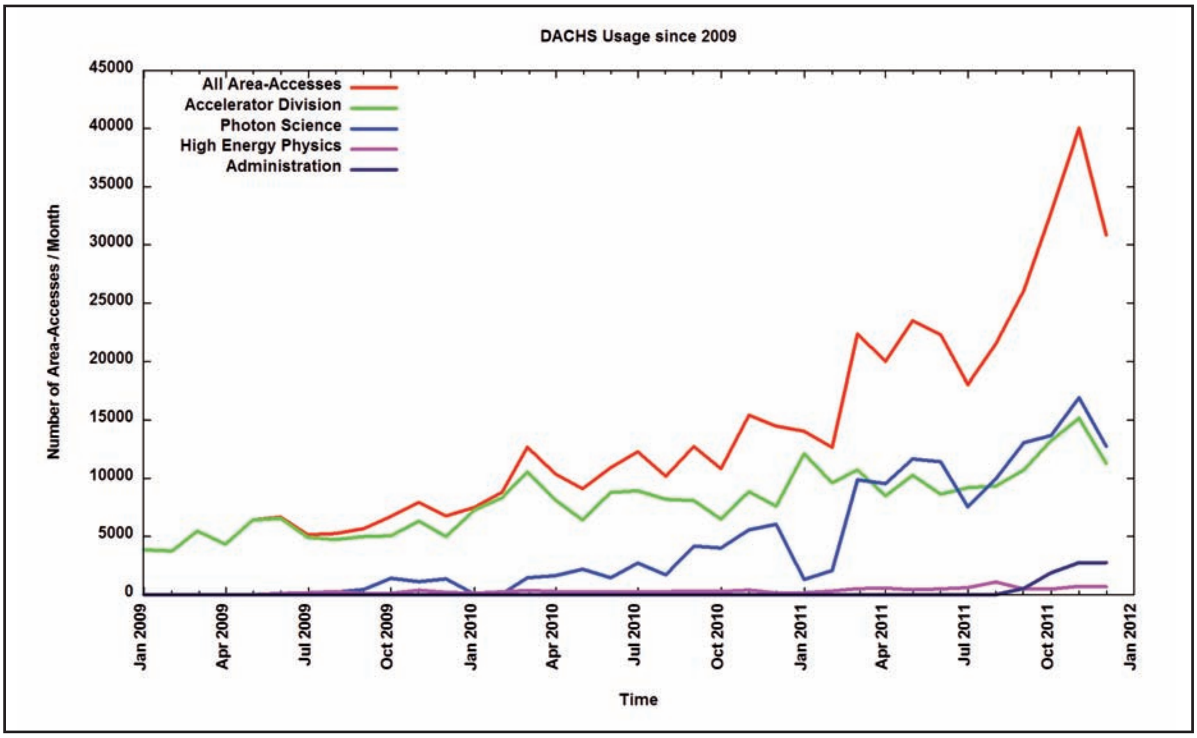

Figure 1
DACHS usage since 2009

the chemical labs of the FLASH hall are now generated. In case of emergency, they provide the technical emergency department und the fire brigade with a list of the persons still present in these areas.

The data exchange with the database for dosimeters was extended. If someone wants to enter an area controlled by the radiation protection department, this person must possess an official dosimeter.

As the European Molecular Biology Laboratory (EMBL) is participating in two beamlines at PETRA III, a special gateway was developed to import external data. Several hundred users per year are expected, so their personal details and the data concerning their instructions must be imported. The gateway is now operated in a test mode and can be extended for other external institutes if needed.

Just before the end of 2011, DACHS was put into operation at DESY, Zeuthen Site, after the labour-management contract for Hamburg had been replaced by a contract for both locations. In Zeuthen, the access control system for the photoinjector test facility PITZ and its control room was commissioned.

Meanwhile, the access to more than 150 areas is controlled and 200 terminals have been installed. Up to now 4 500 cards were issued. They are used more than 30 000 times per month.

Future prospects

The extension of the access controls will continue in 2012. The elegant area search done by a single person will be implemented at the modulator test facilities of the European XFEL. Other halls and workshops as well as the computing centre at DESY, Zeuthen Site, and the experimental areas at the test beams of DESY II will be equipped. The installations for FLASH II and the PETRA III extension are planned. Cost-saving, non-stationary offline terminals will be applied for the first time, so that in the future it will also be possible to equip containers.

In addition, the DACHS team plans the following projects:

- The facilities that provide information to the variety of DACHS users will be extended. In addition to other Info Terminals with additional functions, a public information system is scheduled, which will offer general information concerning the different areas, the requirements needed for access as well as the responsible contact persons.
- In 2012, a new system for a web-based training will be put into operation to reduce the instructors' workload. Simultaneously, instructions can be offered promptly to the employees and guests. This system will be linked to DACHS to operate it as efficiently as possible.
- Besides the commissioning of the EMBL gateway, the upgrade of the commercial software system as well as the implementation of a control panel for the system were assigned highest priority in order to enhance the reliability for day-and-night operation.
- The European XFEL project team is preparing a concept for the access controls of this new accelerator in close cooperation with the DACHS team. Current plans envisage the use of a transponder system because it is necessary to locate persons who are underground. For authentication and authorization, a link to an access control system like DACHS will be necessary.

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Web2cToolkit.

Bringing Web 2.0 technologies to accelerator and beamline controls

Most people associate Web 2.0 with Web services such as Facebook, Twitter, YouTube or Google Maps. However, the paradigms and technologies behind these services are also well suited for operating and maintaining accelerators and beamlines. Web2cToolkit is a collection of Web services. It enables scientists, operators or service technicians to supervise and operate accelerators and beamlines through the World Wide Web. In addition, it provides users with a platform to communicate and to log data and actions.

Motivation

In the past, when accelerator operation stopped due to a broken device, in most cases the technician on call had to come in to intervene and solve the problem on site. With the advent of the Internet, remote inspection or intervention became feasible, provided that a suitable network connection and a properly equipped computer were at hand. Today's Web technologies enable us to get a picture of the current situation and to resolve the problems encountered with much less effort.

The scientists or run coordinators in charge have to know the operation status at any time in order to organize an efficient and reliable operation. Modern Web services are a powerful means to gather remotely, in a simple way, a comprehensive overview, which is a prerequisite for any successful intervention.

The services

Web2cToolkit is a collection of Web services that includes:

- *Web2c Synoptic Display Viewer:* interactive synoptic live display to visualize and control accelerator or beamline equipment (Fig. 1),
- *Web2c Archive Viewer:* Web form to request data from a control system archive storage and to display the retrieved data as a chart or table (Fig. 2),
- *Web2c Messenger:* interface to email, SMS and Twitter,
- *Web2c Logbook:* electronic logbook with auto-reporting capability,
- *Web2c Manager:* administrator's interface to configure and manage the toolkit,
- *Web2c Editor:* graphical editor to generate and configure synoptic displays, and
- *Web2c Gateway:* application programmer interface (HTTP gateway) to all implemented control system interfaces.

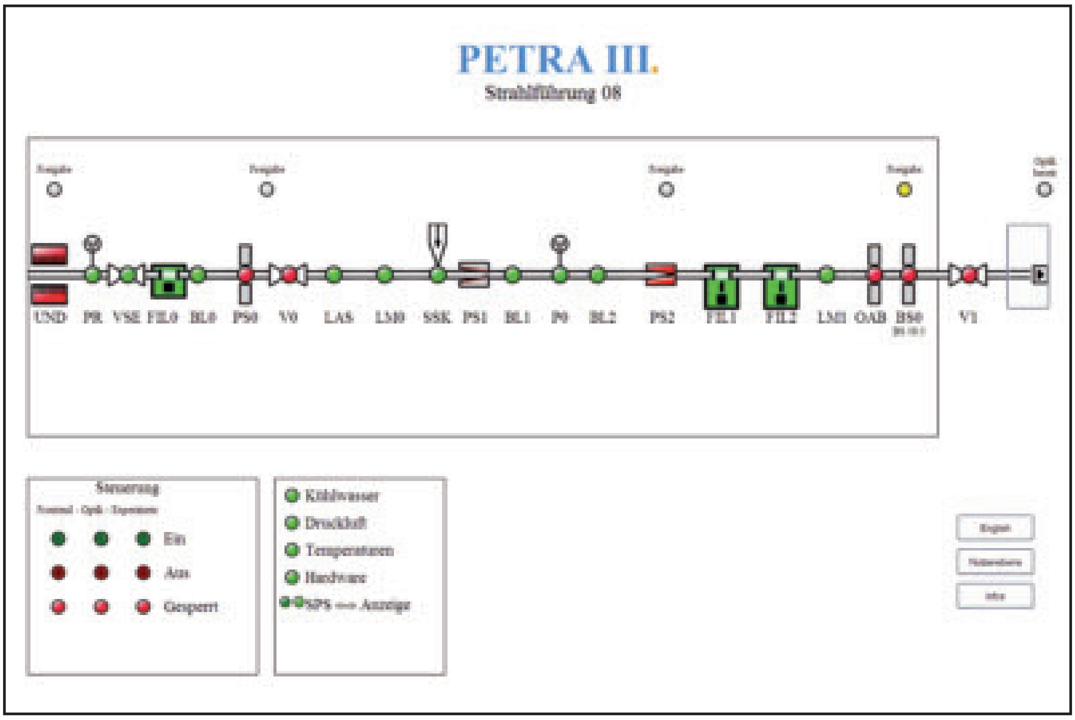

Figure 1

Interactive synoptic live display of vacuum components in a PETRA III beamline

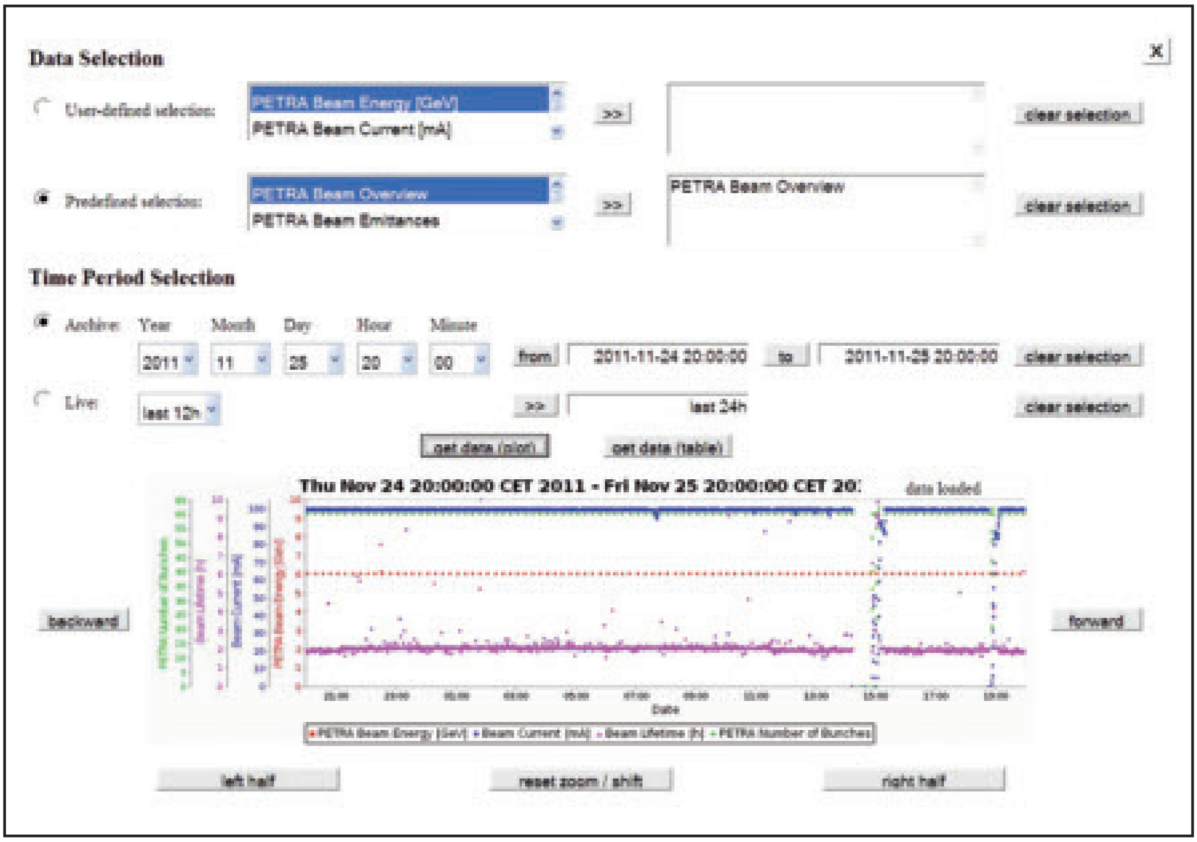

Figure 2

Archive viewer form displaying histories of PETRA III operation parameters

Data Selection

○ User-defined selection: PETRA Beam Energy [GeV] / PETRA Beam Current [mA]

● Predefined selection: PETRA Beam Overview / PETRA Beam Emittances

PETRA Beam Overview

Time Period Selection

● Archive: Year 2011 Month 11 Day 25 Hour 20 Minute 00

from 2011-11-24 20:00:00 to 2011-11-25 20:00:00

○ Live: last 12h

last 24h

Thu Nov 24 20:00:00 CET 2011 - Fri Nov 25 20:00:00 CET 20:

data loaded

Behind the scenes

Web2cToolkit is a framework for Rich Internet Control System Applications. It provides a user-friendly look-and-feel and its usage does not require any specific programming skills. By design, the Web2cToolkit is platform-independent. Its services are accessible through the HTTP protocol from every valid network address if not otherwise restricted. A secure single-sign-on user authentication and authorization procedure with encrypted password transmission is provided. Registered and so-called privileged users have more rights compared to ordinary users (read-only permission).

The Web 2.0 paradigms and technologies used include a Web server, a Web browser, HTML (HyperText Markup Language), CSS (Cascading Style Sheets) and AJAX (Asynchronous JavaScript And XML). The interactive graphical user interface pages are running in the client's Web browser. The interface is compatible with all major browser implementations including mobile versions. The Web2cToolkit services are provided by Java servlets running in the Web server's Java container. To facilitate resource management at the server, the client–server communication is asynchronous and stateless even if each page is bound to a session in order to facilitate resource management at the server.

The Web2cToolkit provides interfaces to major accelerator and beamline control systems including TINE, DOOCS, EPICS and TANGO. Both TINE and DOOCS are hosted by DESY. The toolkit is capable of receiving and processing JPEG-type video streams.

By the way

Twenty years ago, PC technology started to become popular in accelerator and beamline controls. DESY is a pioneer and trendsetter in this respect. The technology has massively changed the way of working in control rooms and laboratories. Today, once again fast-paced technological developments are beginning to show up in accelerator and beamline controls: mobile high-performance end devices, touch-sensitive screens and finger gesture recognition, virtual three-dimensional device control or powerful speech recognition. Again, this will change how we operate accelerators and beamlines and will offer novel opportunities to present and handle the required information.

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Useful links

Web2cToolkit: http://web2ctoolkit.desy.de
TINE: http://tine.desy.de
DOOCS: http://doocs.desy.de

The third DESY accelerator ideas market.

Follow-up of a brainstorming activity

To promote the development of novel concepts for future accelerators, DESY launched an “accelerator ideas market” in June 2010. The third such ideas market took place in mid-September 2011. The large number of about 70 enthusiastic participants reflected the continuing strong interest in the event.

Figure 1

As in the previous years, there were many fruitful contributions also to this third DESY accelerator ideas market.

As in the previous two events, all DESY employees and users interested in accelerator research and development at DESY were welcome to present their new ideas in short talks not exceeding ten minutes, with a subsequent five-minute discussion. After the meeting, a team of experts evaluated the ideas with the help of a questionnaire.

For an increasing number of ideas presented at the previous meetings, teams working on their realization have been formed. This is particularly the case for new accelerator concepts like plasma acceleration, for which several follow-up contributions with new and more specific ideas were presented. Work was also carried out on accelerator concepts based on superconductivity, for example aiming at continuous-wave operation of accelerating modules originally designed and developed for pulsed operation. In addition, new ideas and first results for new beam diagnostics methods were presented. Some ideas for new concepts and technologies and for further development of present accelerator technology have become part of the Helmholtz Accelerator Research and Development (ARD) programme.

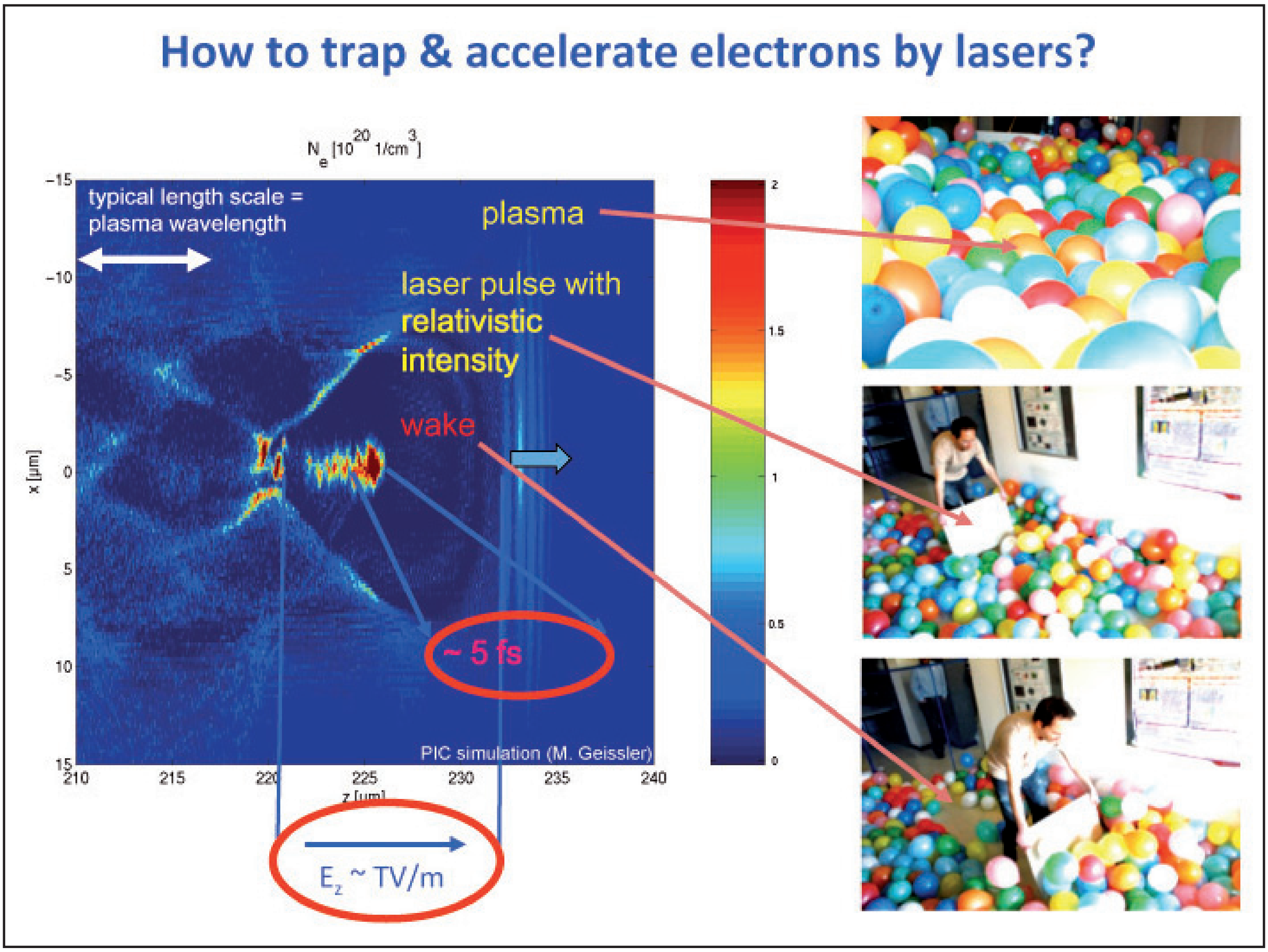

Figure 2

Colourful illustration of the principle of laser plasma acceleration. [Courtesy Dr. Michael Geissler (Queens University Belfast)]

The second category of ideas is driven by pure particle physics research questions. These ideas included a Z factory, a short linear collider as a low-energy Higgs factory in consequence of the exclusion of a medium-energy Higgs by recent LHC data, and using electron beams from existing superconducting linear accelerators at DESY for detector testing. Obviously, work performed on ideas for large-scale accelerator complexes is mainly conceptual and much less on hardware, due to the financial demands of such installations.

A possible large-scale industrial application of the FLASH technology for the next generation of microlithography technologies was also proposed. The wavelength range around 13.5 nm and 6.x nm, which is generated by the FLASH free-electron laser, meets exactly the future requirements of these printing technologies. An increase of the average output powers up to 2.5 kW seems to be feasible. This opens the way for cost-effective high-volume manufacturing.

Like the previous meetings, the 2011 DESY accelerator ideas market was a very fruitful source of new ideas, which are of great importance for the future of the laboratory. The next ideas market is planned to take place in late summer 2012.

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LAOLA – the Laboratory for Laser- and beam-driven plasma Acceleration.

Perspectives of unique plasma wakefield studies at DESY

Accelerator physics experiences the rise of a new field: plasma wakefield acceleration (PWA). The perspectives are obvious: ultrahigh field gradients and intrinsically ultrashort bunches, both of which have been measured at various laboratories across the world. However, PWA still suffers from a poor beam quality when compared to modern, conventional accelerators. Therefore, merging modern accelerators with PWA holds promise for directly probing the wakefields to better control PWA schemes. The aim is to drive brilliant light sources and possibly, in the far future, even high-energy colliders.

PWA has already demonstrated field gradients on the order of a few 100 GV/m and bunch lengths on the order of a few femtoseconds – in other words, "dream beams". However, the beams' quality still suffers from mainly a too large energy spread. This is directly linked with the injection of the plasma electrons into the wakefield. Because of the compactness of the accelerator structure (basically, one plasma period), a bunch that covers a large fraction of the accelerating part of the wakefield will eventually leave the plasma with a broad energy range. In laser-driven PWA schemes, there is self-injection of the electrons. This, however, implies that the initial state of the trapped electrons is unknown – and so far inaccessible to experiments. LAOLA, the Laboratory for Laser- and beam-driven plasma Acceleration, thus aims at probing the wakefields with well-known bunches from external accelerators (REGAE and, later on, FLASH). Another task is foreseen at DESY, Zeuthen Site. Here, we will make use of the photoinjector test facility PITZ and generate a train of specially shaped bunches to study the prerequisite of the planned CERN concept of proton-driven PWA: the self-modulation of the driver beam.

In early 2013, we will install a 200-TW high-power laser adjacent to the REGAE lab. This laser can be used to generate a plasma wakefield in a capillary filled with gas, into which external bunches from the REGAE gun, synchronized relative to the driver laser, will be injected. This will be a unique possibility for DESY to study PWA: probe the wakefield with a well-known external bunch.

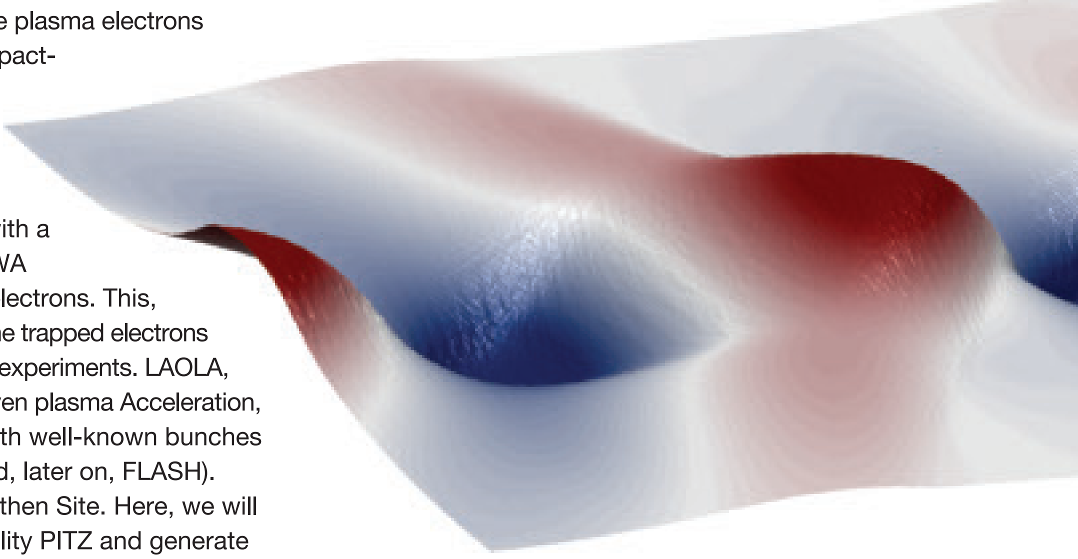


Figure 1

Computer simulation of a laser-driven plasma wakefield. The figure shows the longitudinal component of the electric field. Electrons can be accelerated in the blue regions. The laser field can be seen on the right hand front side. [Courtesy of Timon Mehrling]

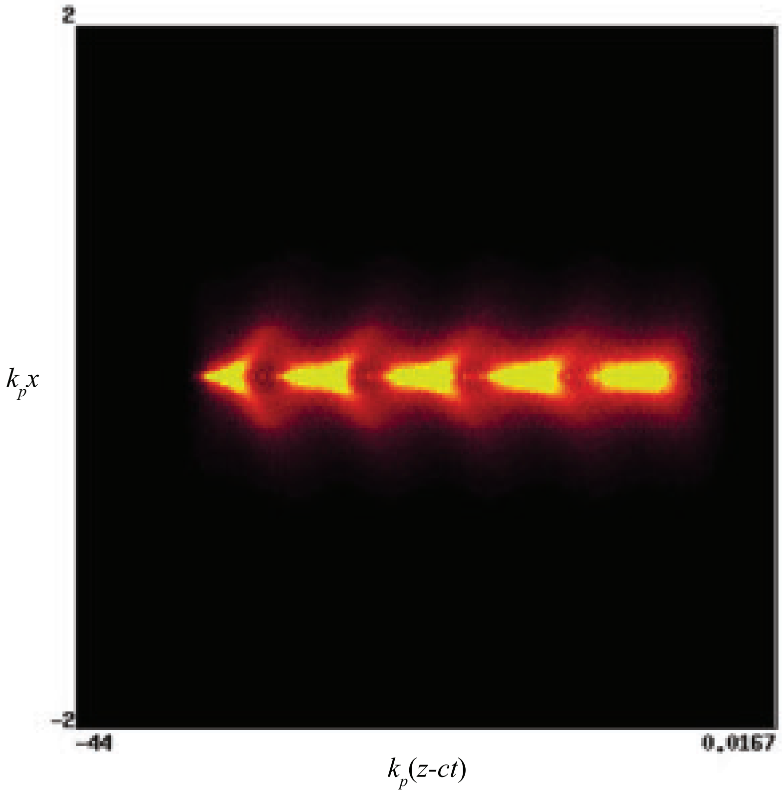
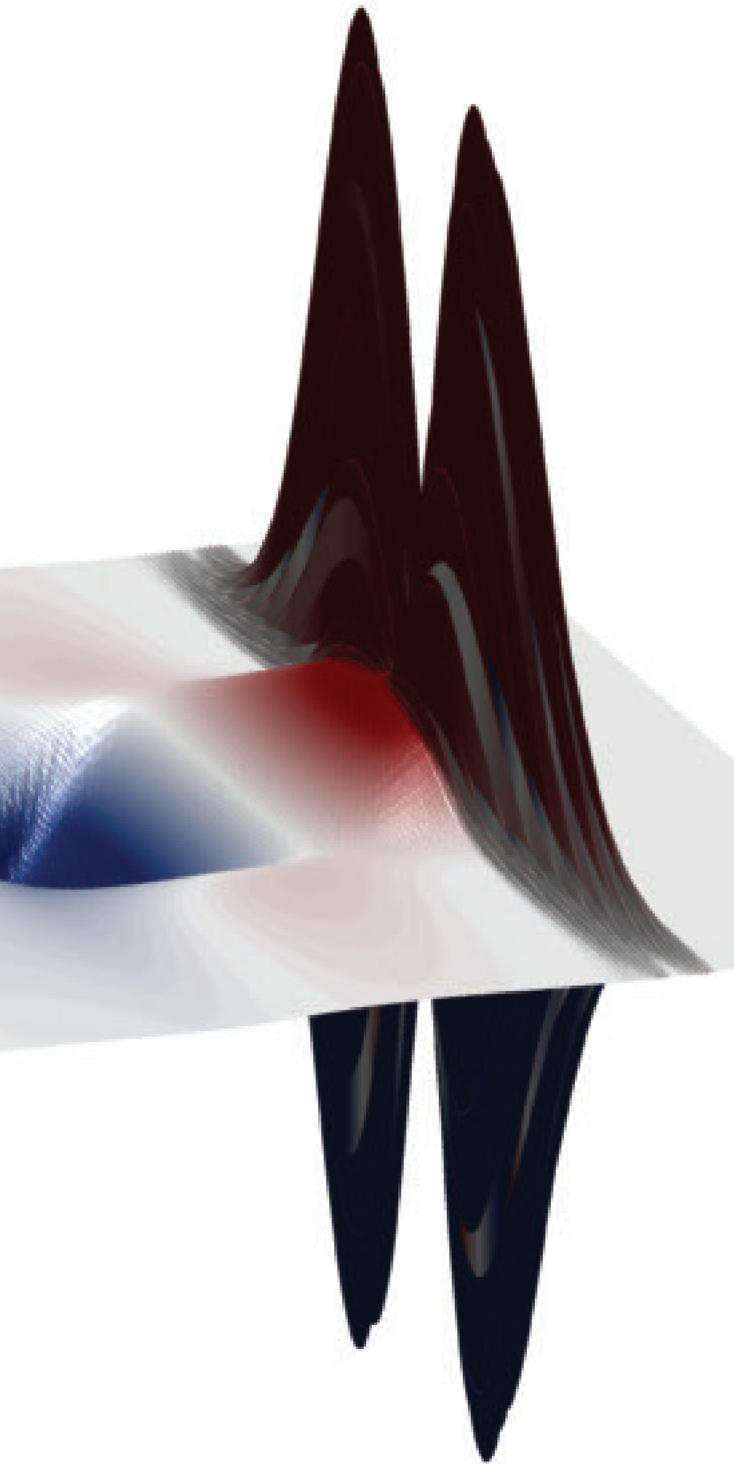


Figure 2

Simulation of a self-modulated PITZ beam after traversing 2 cm of plasma. The simulation nicely shows the separation of the beamlets by one plasma period. [Courtesy of Carl Schroeder]



The beam self-modulation experiments at DESY, Zeuthen Site, will be prepared in parallel. The major task here is the development of a plasma cell and diagnostic tools for a plasma density range that is yet unusually low for laser-driven PWA. The reason is that the (relatively long) plasma period needs to be matched with at least the rising edge of the bunches generated by the photoinjector. In cooperation with the group of Dr. Wim Leemans from Lawrence Berkeley National Laboratory, we have studied the theoretical conditions for the onset of self-modulation for the PITZ electron beam.

The possibilities at FLASH are manifold: one type of experiment will continue the studies at REGAE, that is, injecting the GeV-scale electrons of FLASH and further boosting their energy while measuring the emittance and other beam parameters. This will be a prerequisite pilot study for any future high-energy collider schemes based on PWA. The other major task is to study beam-driven PWA, aiming at a large transformer ratio and shaping the witness bunch in such a way that by its beam-loading, the wakefield is flattened for a reduced energy spread.

LAOLA is a collaboration of various DESY and Hamburg University groups, organized by a board of project coordinators. The main funding comes from the Helmholtz Accelerator Research and Development (ARD) programme and from Hamburg University. More information can be found at laola.desy.de.

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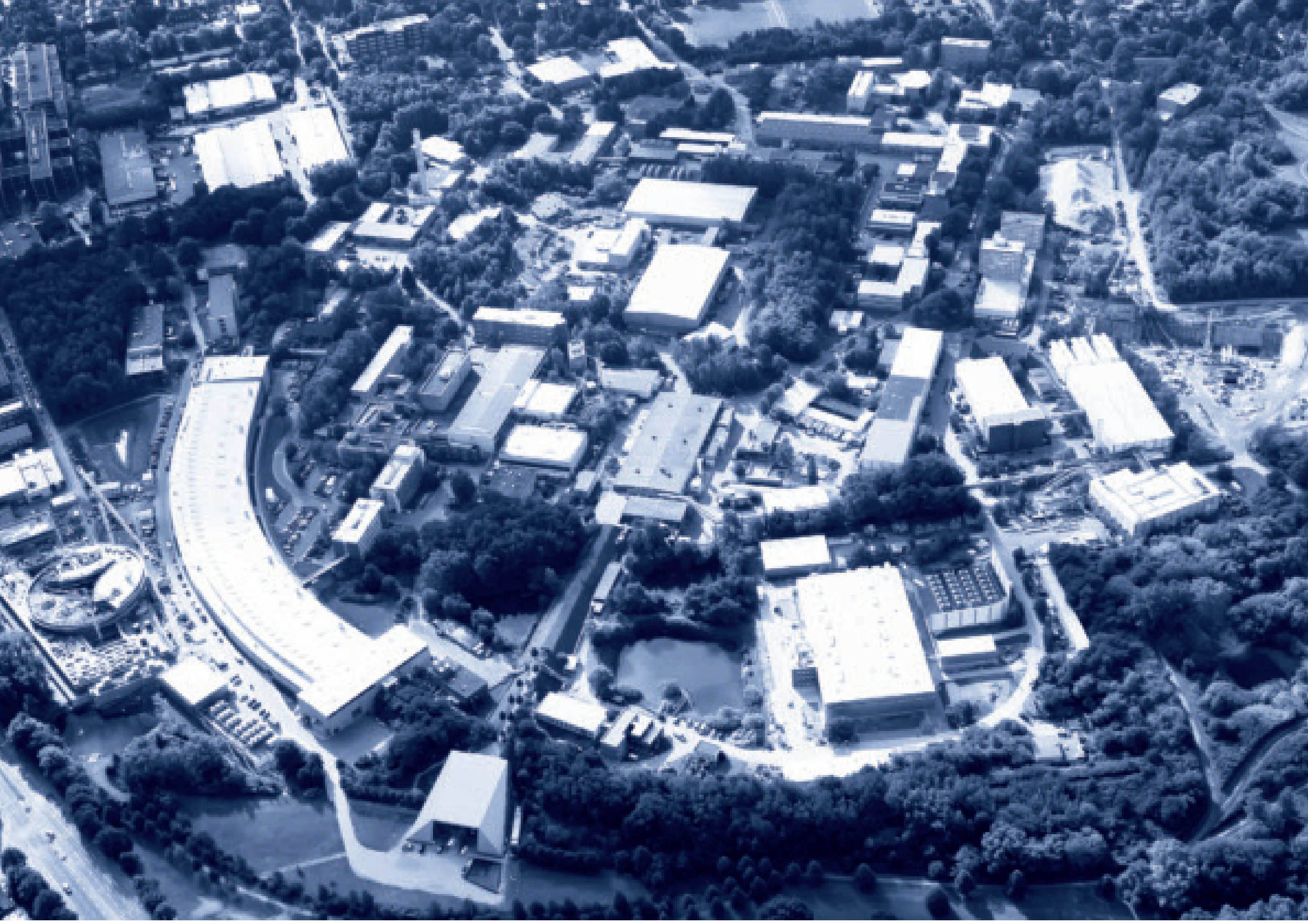

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