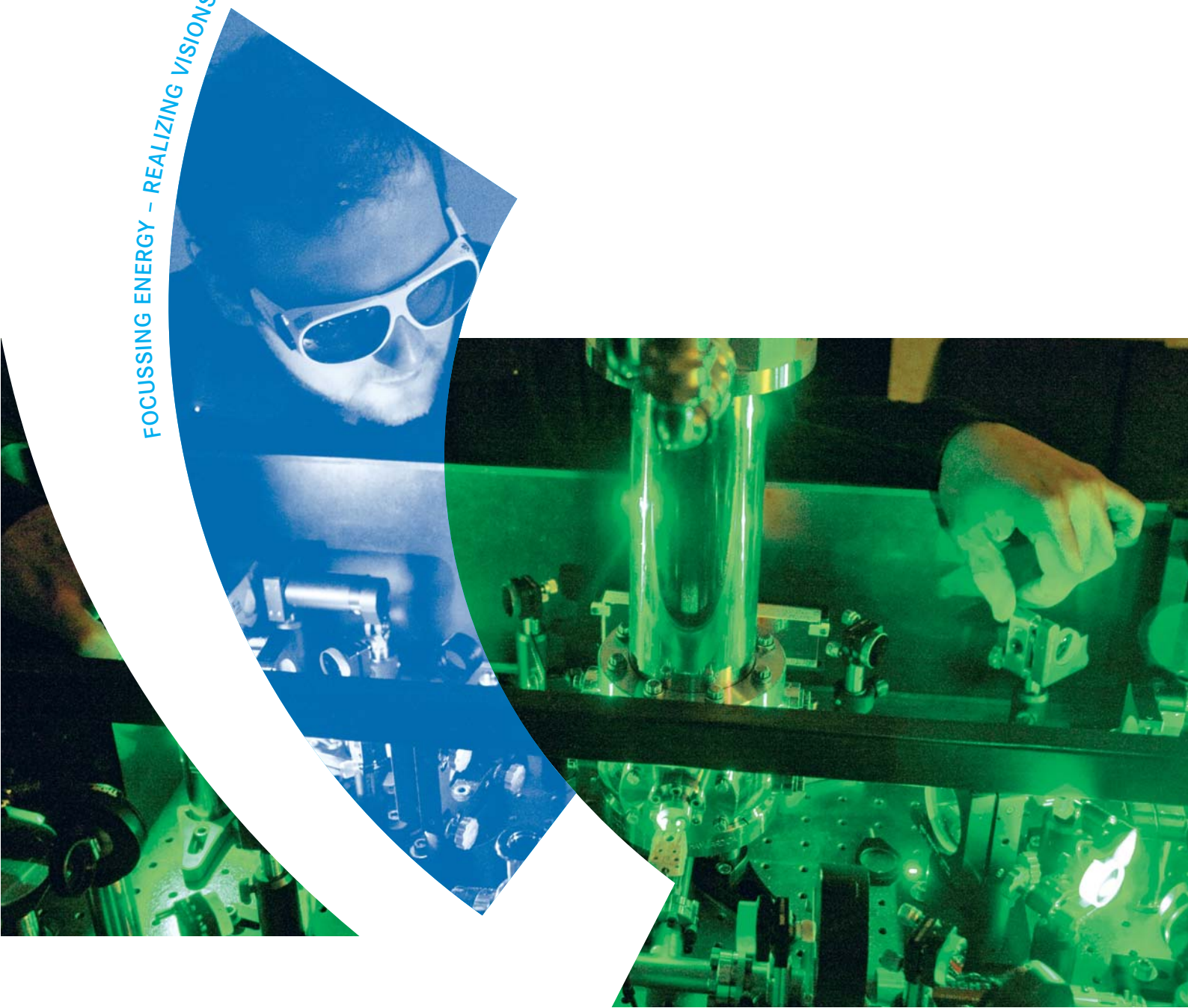


FOCUSSING ENERGY – REALIZING VISIONS



BERLinPro

Using electrons in research for the future

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“TO BE ABLE TO PURSUE A NEW COURSE IN BASIC SCIENCE RESEARCH AND DEVELOP CONCEPTS THAT ADDRESS AND HELP SOLVE OUR GLOBAL PROBLEMS, SCIENCE IS IN NEED OF A NEW VANTAGE POINT CAPABLE OF CUTTING ACROSS ITS VARIOUS DISCIPLINES. WITH BERLinPro, HZB WILL DO ITS SHARE TO HELP REALIZE THIS VISION.”

*Professor Dr. Anke Kaysser-Pyzalla,
Scientific Director, Helmholtz-Zentrum Berlin*



ACCELERATOR TECHNOLOGY TODAY

Research today finds itself confronted with humanity's biggest questions

Research at the Helmholtz Association is addressing today's most pressing challenges where Helmholtz scientists aspire to gain insight that will improve our society. The researchers are currently exploring new energy concepts, discovering materials with new and improved properties, and examining the etiology of different diseases and new methods for their treatment.

Our scientists are looking for answers on the microscopic scale – from molecules and atoms, and even the miniscule building blocks they are made of

One of the most important research tools available today are particle accelerators. With the help of the world's largest, the Large Hadron Collider (LHC) – operated by the European Organization for Nuclear Research (CERN) in Geneva, Switzerland – scientists are currently investigating the structures of the smallest-size building blocks of matter and the elementary forces, which hold them together.

Molecules, crystals, and magnetic structures are examined using light (X-ray, ultraviolet, or infrared) that is generated by synchrotron light sources such as HZB's BESSY II. These types of light sources, in which accelerated electrons emit light, enable new insights across the entire spectrum of scientific disciplines – from solid state physics to biochemistry and materials science, to archeometry and zoology.



Synchrotron light enables us to address fundamental research questions

Synchrotron light has helped answer many fundamental research questions, such as:

- Clarification of the structure and function of ribosomes, cellular components that are in charge of translating mRNA's copy of the original DNA code into proteins
- Detailed examinations of the flow of catalytic processes
- Structural analysis of magnetic materials.

Scientific breakthroughs in these areas have culminated in Nobel Prizes (Yonath, Ertl, Grünberg) and hold tremendous potential for the future of computer technology, fuel cells, and the development of antibiotics. For these, as well as many other areas of basic science research, synchrotron radiation sources are indispensable.

Particle accelerators in practice

The list of scientific breakthroughs that rely on particle accelerators (and which ultimately resulted in practical applications) is amazingly long. In radiation oncology, for example, particle accelerators are used to shrink tumours. Currently eye tumour therapy is performed in conjunction with the Charité at HZB's Lise-Meitner-Campus in Berlin-Wannsee. Similarly, security technology, which is used to safeguard international trade, utilizes x-ray radiation based on electron accelerators and neutron emission from ionic accelerators. Furthermore, the availability of high-intensity electron beams has spurred the development of new welding techniques used to construct high-tech devices.

ACCELERATOR TECHNOLOGY TOMORROW

From statics to dynamics ...

In spite of the many successes, research using third-generation synchrotron radiation sources has largely been limited to investigations of the static, structural properties of matter. In other words, researchers can determine the electron distribution or molecular structure of matter in an equilibrium state, but they are unable to analyse the dynamics of atomic and subatomic processes. These processes are essential to gain a better understanding of how these systems actually “function.” In order to gain insight into this world, scientists must be able to work with light pulses on increasingly short time scales, on the order of femto-seconds – shorter than the amount of time it takes a ray of light to brush past the width of a human hair!

... from structure to functionality

Having the ability to simultaneously record images of a sample’s structure and its dynamic processes would allow researchers to truly understand the functionality of different materials. Combining these images with exposure times on the order of femtoseconds would further enhance the researchers’ understandings of materials at the atomic level.

- The variability of matter on atomic and subatomic levels is the epicentre of novel materials like those employed in magnetic and optical storage media.
- Chemical and biological processes rely on the interplay between atoms, electrons, and their spins. By understanding this interplay, scientists can develop novel functional materials necessary for energy storage, thin-film solar cells, and materials for regenerative medicine. In order to accomplish this, researchers will rely on a variety of different observational tools made possible by particle accelerator technologies.

New accelerator concepts like free-electron lasers (FELs), ultimate storage rings (USRs), and the synchrotron radiation source of the future – the Energy Recovery Linac (ERL – a linear accelerator, or Linac, capable of energy recovery) will advance material science research one step closer to reality.

Science is in dire need of a new accelerator technology

The Berlin Energy Recovery Linac Project, or *BERLinPro* for short, is a feasibility study that allows HZB and partners from around the world and the Helmholtz Association to develop next-generation accelerator concepts and technologies.

Ultimately, a synchrotron-radiation source based on *BERLinPro* technology will provide the international research community with a complete picture of molecules, atoms, their surfaces and their building blocks. This insight will essentially reveal the inner-dynamics of molecular, atomic, and subatomic processes.

BERLinPro in the spirit of the Helmholtz mission
“Research conducted at the Helmholtz Association is aimed at ensuring society’s long-term existence while creating the technological basis for a competitive economy.”

The aim of *BERLinPro* is to raise the performance of ERL technology to a new level. *BERLinPro* holds the key to providing the international research community with important new tools to help address humankind’s most urgent questions. *BERLinPro* will serve to permanently enhance the Helmholtz Association’s international reputation as well as that of its partners.



“WE ARE HOPING TO BE ABLE TO USE *BERLinPro* TECHNOLOGY TO GAIN NEW INSIGHTS INTO THE FUNCTIONS OF BOTH LIVING AND INANIMATE OBJECTS.“

*Professor Dr. Alexander Föhlisch,
Director, HZB Institute Methods and
Instrumentation for Synchrotron
Radiation Research*



***BERLinPro* – THE POTENTIAL**

***BERLinPro* combines the advantages of different accelerator concepts**

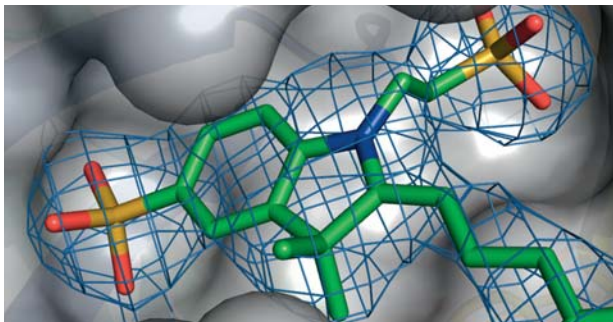
Today's research has at its disposal state-of-the-art light sources in the form of storage ring light sources – whose development has helped produce USRs that are presently under construction – as well as FELs. ERL technology successfully utilizes the best qualities of two light sources, the FEL and USR. The ERL combines the brilliant, ultra-short light pulses of an FEL while simultaneously utilizing the USR's high-repetition rate and large number of photons. This allows a material's structure to be examined, while completing dynamic experiments that neither moves nor destroys the sample. Most importantly, an ERL-based light source would be highly flexible. It can adapt to the different demands made by the type of experiments that are carried out at any given time.

The critical advantage of ERLs is that a large number of measuring stations can be available to several research groups simultaneously – in the same fashion as the previous and successful storage-ring-based sources. This advantage is essential given the high-investment costs for such machines and the fact that user demand for beam time far exceeds what is available at existing light sources.

ENERGY

We need new energy concepts

To allow our society to continue to develop new technologies, we are in need of new concepts and materials for energy generation and energy storage. Solar cells, fuel cells, energy accumulators, and catalysts are merely a few of the systems that must be further developed. In tandem with the development of new energy systems, we must also better manage the energy that is available to us. Weight reductions of vehicles, increased efficiency of energy usage in transportation, and optimized insulation for thermal processes are just a few possibilities. To achieve this, scientists need increasingly detailed information regarding the internal structure and dynamic behaviour of matter at the atomic level. This research requires a “multi-dimensional” view of the building blocks of these materials, and a new light source using *BERLinPro*-technology offers these opportunities.



HEALTH

Modern medicine without particle accelerators is unthinkable

Particle accelerators are used in cancer therapy to destroy tumour cells. Accelerator-based systems are capable of producing high-contrast images of the human body and its internal organs. These images are used to analyse the effects of radiation on biological tissues and to generate radioactive isotopes for the diagnosis and treatment of tumours and joint diseases. Synchrotron radiation sources allow insights into the structure and functionality of biomolecules such as proteins, which contribute to a better understanding of disease and help with drug design.

The new molecular dimension

With BERLinPro's ERL-based accelerator concept, the medical application of accelerators opens a new molecular dimension. It allows for real-time observation of cellular systems and also the ability to witness more clearly, the function of proteins at the molecular level. Scientists are able to examine cells' responses to pathogens in order to gain a better understanding of the etiology of disease. ERL technology can help to open up new horizons in both basic science and everyday applied medicine. Using conventional x-radiation sources, physicians are only able to visualize soft tissues using contrast media and sophisticated software solutions. These methodologies often have less than satisfactory results as the beams' characteristics are neither a sharp energy profile nor a small enough cross-sectional area. Changes in coronary vessels or the lungs – both of which are associated with several common diseases – can only be detected at the expense of great stress to the patient. An ERL-like electron source that is driven by a high-intensity laser beam will produce the required x-ray beam quality and it would be compact enough that it could realistically be installed in hospitals.

MATERIALS

Custom configuring structures at the nano scale

Whether it is high-performance computers, minimally invasive surgical methods or molecular magnets, science and engineering over the last few years have scored enormous successes thanks to accelerator technologies. But as the miniaturization trend continues, we continuously need new functional materials such as nanostructures, novel combinations of normally immiscible solids, biocatalysts and alternative energy storages.

To develop these, scientists must be able to observe the structure of the material, its dynamics, and chemical reactions in real-time. Only after this has been accomplished will scientists truly understand the function of materials. From here, they will learn how to optimize the materials for a given application. A next-generation ERL is the key to this type of research.

ART AND HISTORY

Accelerators offer a precise view into the past ...

Precision archeometry with accelerators

It is possible to use particle accelerators for verifying a painting's authenticity or for determining a work of art's original date of production. Similarly, researchers are able to date fossilized organisms with great precision, allowing the ability to reconstruct the fossils' evolutionary family tree. The expectation is that new accelerator technologies will yield considerable progress in this field over the next years. It will eventually become possible to reconstruct historical and cultural contexts with great precision, analyse human prehistory better than before, and more accurately characterize the progression of evolution.

“BERLinPro WILL FINALLY ALLOW US TO CAST OFF THE SHACKLES OF THE STORED ELECTRON BEAM.”

*Professor Dr. Jens Knobloch,
Director, HZB Institute of
SRF Science and Technology*



NUCLEAR PHYSICS

In nuclear and hadronic physics, scientists aim to probe the structure of matter

Protons and neutrons – both of which belong to the category of hadronic elementary particles – are the subatomic building blocks of atoms which make up the world around us. Researchers seek to understand how these particles function, why they bond together, and what they are made of. To study these nuclear building blocks, scientists perform “collision experiments.” One class of experiments currently being formulated are upgraded concepts of CERN’s LHC (LHeC) and Brookhaven National Laboratory’s RHIC (eRHIC) experiments that collide electrons and hadrons. The more sharply an electron beam can be focused, the greater its intensity, which allows more to be learned from the experiment. Unlike in storage rings, an ERL’s beam parameters are not intrinsically limited which allows for greatly enhanced beam intensities. BERLinPro technology opens up a whole new world of collision experiments.

COLD ION BEAMS

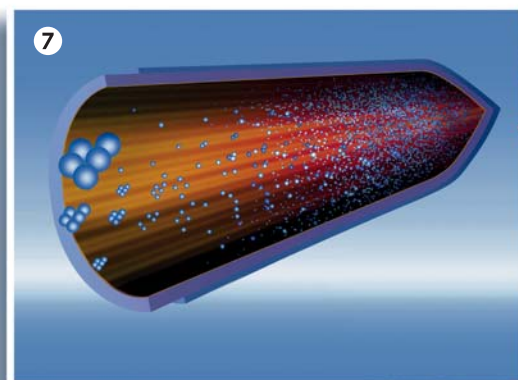
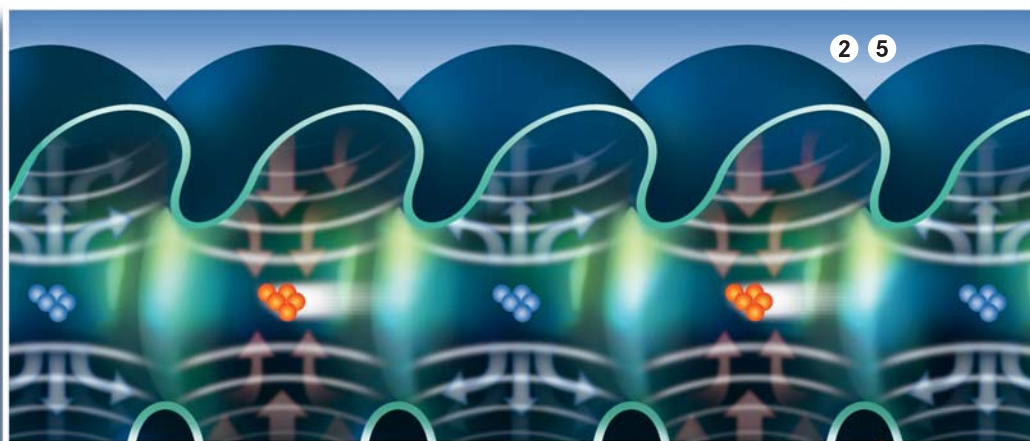
BERLinPro technology to “cool” ion beams

Electrons are used to enhance the quality of ion beams, which are again used in an effort to better understand the interplay of nuclear building blocks during collision experiments. If, for instance, scientists generate an accelerated gold ion beam, it would occupy a large volume, be unfocused, and the ions would be “tottering” through the storage ring. Therefore, scientists also use a second superimposed beam of electrons that all move in a rectilinear fashion (the beam is considered “cold”) in order to “cool” the ion beam while the electrons “heat up” and become jittery. As a result, a straighter gold ion beam with a smaller cross-sectional area is produced. The more intense and the more parallel the initial electron beam is, the better the resulting ion-beam quality becomes, which improves the efficiency of the actual experiment. Existing facilities are based on electrostatic electron acceleration, which cannot be used for the cooling of high-energy ion beams. An ERL’s high-intensity, brilliant beams would be able to circumvent this limit.

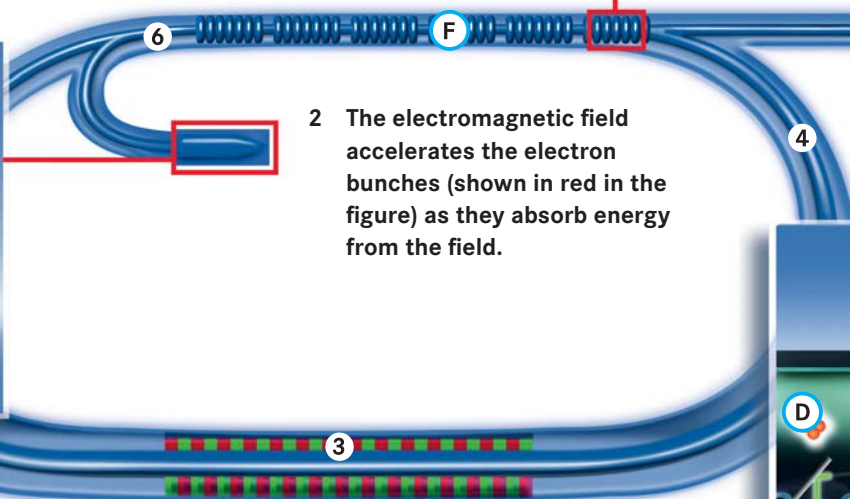
THE ERL PRINCIPLE

5 In the opposite field, high-energy electron bunches are decelerated, returning their energy to the field (electron bunches are shown in blue in the figure). The returned energy can be “recycled” for acceleration of the red packets.

6 The decelerated electron packets are directed to the beam stopper.



7 Inside the beam stopper, the journey ends: the decelerated electrons are absorbed in a water-cooled copper wall.

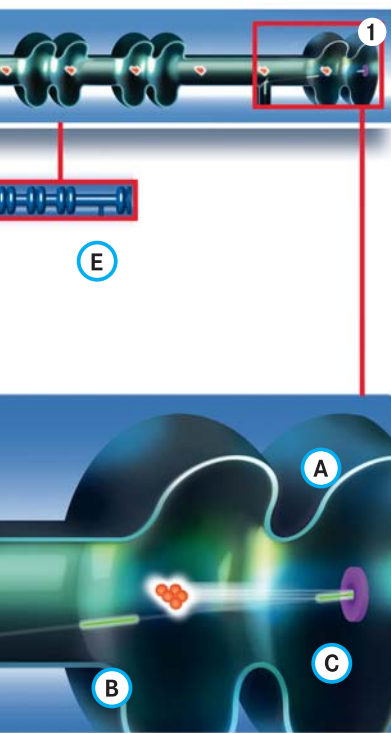


2 The electromagnetic field accelerates the electron bunches (shown in red in the figure) as they absorb energy from the field.

3 An ERL electron beam has multiple applications. One option is to produce synchrotron light in an undulator.

- A Superconducting photo injector used to produce the electron beam.
- B Laser pulse
- C Photocathode for electron emission
- D Electron packet
- E Injection straight consisting of superconducting electron source and pre-accelerator
- F Main accelerator with superconducting cavities

- 1 A laser beam knocks electron bunches out of the photocathode.**



Britta Mießen, Köln

- 4 Magnets direct the electron bunches along an arc back to the cavities.**

A superconducting high-energy source to produce brilliant, high-intensity beams

A linear accelerator works similarly to a classic television set. Inside a television tube, electrons are released from a glowing wire in a vacuum. They are then accelerated by an electric field and collide with the screen's inner surface to produce light (the TV image). Something similar happens inside BERLinPro, (albeit inside liquid-helium-cooled superconducting cavities) with the added difference that the electrons receive an energy that is 2000 times greater than that of a television tube. Furthermore, the electrons do not originate from a glowing wire but from a superconducting high-energy source that is capable of producing much more brilliant, high-intensity beams.

Standing waves: superconducting continuous wave technology

Cavities are curved metal "tubes" made of superconducting niobium, where microwaves bounce back and forth inside 1.3 billion times a second. At the end of the tube they are reflected. When their wavelength is exactly tuned to the length of the metal tube, a very strong electromagnetic field called a „standing wave“ is established. Electrons that fly into this field at the right moment absorb some of its energy. Once they have moved through all of the cavities, their energy is equivalent to an acceleration of 50 million volts – greater than the energy charges receive in a thunderstorm. The energized electrons now fly into the beam transport system, which delivers the beam to the scientific experiments.

Energy recovery

The energy recovery principle works as follows: At the end of their flight through the beam transport system, the electrons carry a large amount of power – anywhere from 5 MW (as is the case with the BERLinPro) to several hundred MW in larger ERLs. For this reason, ERLs cannot simply discard the electrons following the experiment. Rather, the beam is recirculated back to the cavities where the electrons arrive precisely at the time when the electromagnetic field is oriented in the opposite direction. The electrons are now decelerated rather than accelerated and therefore give off energy to the field inside the cavities. The beam's energy is thus recovered and is available to accelerate a fresh electron beam. This allows for production of an electron beam with exceptional parameters without having to operate a dedicated power plant for the accelerator.

Once they have given off their energy, the decelerated electrons fly out of the cavities into the beam stopper, where they meet a water-cooled copper wall. The minimal remaining energy is converted to heat and their electric charge is drained off into the Earth in the form of an electric current.

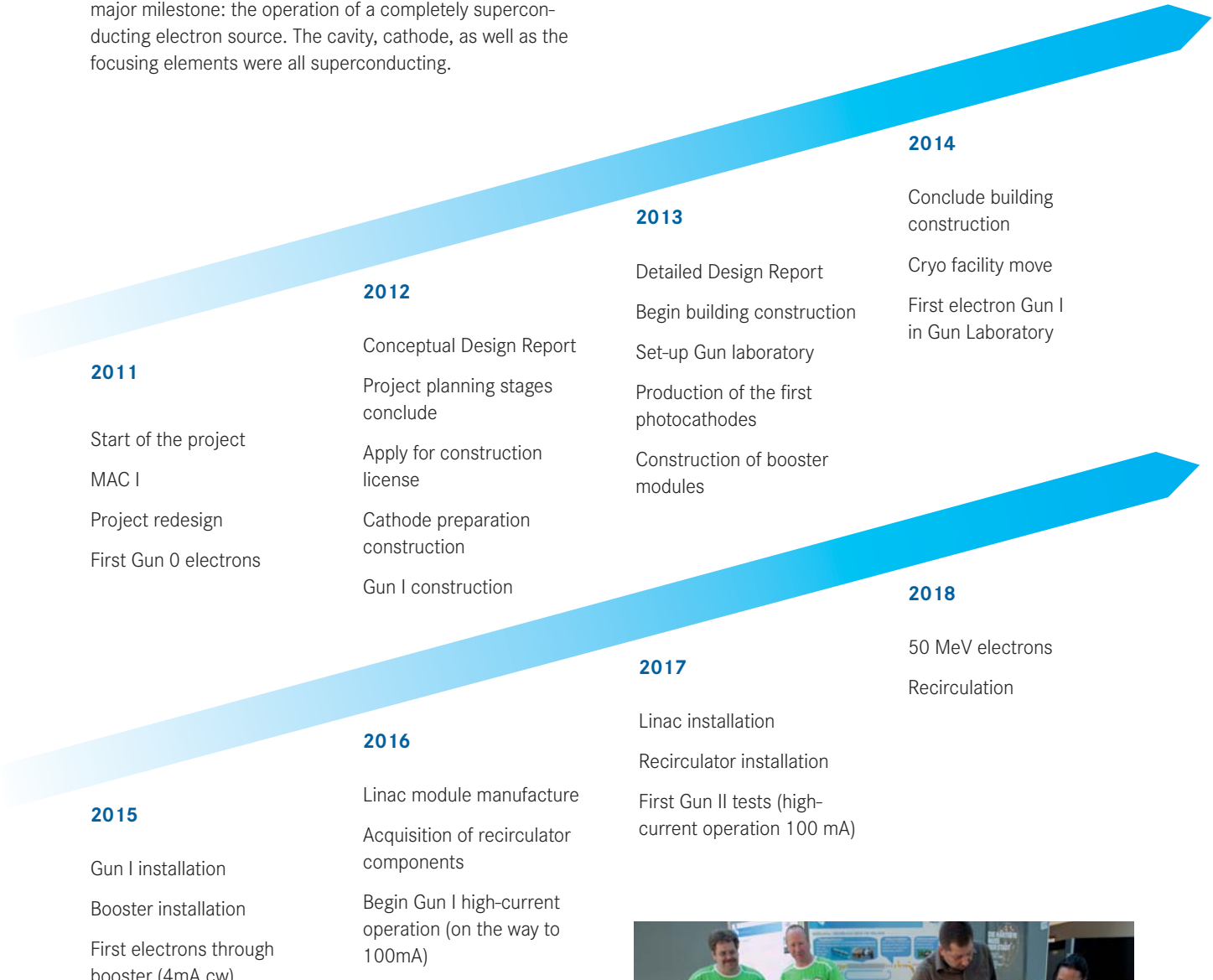
WHAT'S BEEN HAPPENING – AND WHAT'S GOING TO HAPPEN

In fall 2010, the Helmholtz Senate, the Association's highest decision-making-body, unanimously recommended the realization of the *BERLinPro* project under the aegis of the Helmholtz-Zentrum Berlin (HZB). Funding is provided by the Helmholtz Association for strategic investments, the State of Berlin, and HZB.

The completely superconducting electron source

The following year, HZB, DESY, Jefferson-Lab, and Poland's Soltan-Institute scientists were already able to achieve a first major milestone: the operation of a completely superconducting electron source. The cavity, cathode, as well as the focusing elements were all superconducting.

Although this particular "Photoinjector" will not ultimately be used to drive *BERLinPro*, it has nevertheless advanced the team's know-how, upon which further generations of photoinjectors are now being based. Consequently, since early 2012 the research focus has been on developing a *BERLinPro*-applicable photoinjector.. Working closely with HZB's partners, the design for the main Linac cavities has to be developed as well – with the goal that by 2018, *BERLinPro*'s feasibility will be demonstrated.



“WITH BERLinPro WE ARE WRITING A NEW CHAPTER IN ACCELERATOR TECHNOLOGY – NEW POSSIBILITIES WILL OPEN UP THAT WE CANNOT YET FULLY FATHOM.”

*Professor Dr. Andreas Jankowiak,
Director, HZB Institute Accelerator Physics*



HZB – THE RIGHT PLACE FOR BERLinPro

BERLinPro and the HZB strategy

Research into new accelerator technologies is an integral part of HZB's strategy. As an operator of large-scale facilities, the Helmholtz-Zentrum Berlin is heavily involved in technology development in order to consistently offer its users the most optimal research conditions. In this context, BERLinPro is doubly significant. On one hand, it serves as the basis for a new generation of light sources; and on the other, BERLinPro also affords important new insights, such as in the area of continuous wave SRF technology (CW). This can be used to improve existing accelerators such as HZB's BESSY II or those at other research institutions. BERLinPro represents progress for tomorrow's scientists and for today's operators of large-scale equipment.

New scientific territory through the use of current innovations

With the BERLinPro study, the HZB specialists have ventured into new scientific territory. While machines already exist that are capable of realizing the principle of energy recovery, they offer only a glimpse of the parameters that will ultimately be possible once ERL technology's full potential has been unlocked. For example, a next generation x-ray source is a possibility. For this, HZB researchers would like to see at least a tenfold increase in the electron beam current and also in the beam quality. This will help open up new prospects, unexpected turnarounds, and new research worlds.

“ACCELERATOR TECHNOLOGIES HAVE TO BE RAPIDLY ADVANCED, WHICH IS WHY WE ARE POOLING THE COMPETENCIES OF – AND EXPANDING THE INTERCONNECTEDNESS BETWEEN – THE GERMAN RESEARCH INSTITUTIONS.“

*Professor Dr. Jürgen Mlynek,
President, Helmholtz Association*

Expertise at HZB

Collectively, HZB scientists pool the expertise needed for success. The application of CW SRF with multi-cell cavities has been significantly advanced by the HZB research team at the HoBiCaT facility. Superconducting CW RF technology is essential for ERL development. Beyond this, HZB is an internationally acknowledged leader in the construction of novel undulators (special magnetic systems capable of producing particularly brilliant radiation when electrons fly through them). HZB has extensive expertise in simulating accelerator designs and has more than 30 years of experience operating synchrotron light sources such as BESSY II, the metrology light source MLS and the proton accelerator for eye tumour therapy. HZB is truly in a unique position to develop BERLinPro.



HZB AND BERLinPro AS PART OF THE HELMHOLTZ ASSOCIATION

Portfolio topic “Accelerator Research and Development”

The Helmholtz Association is a German scientific organization charged with development and operation of large-scale facilities and the related technology through feasibility studies of the calibre of the *BERLinPro* project. *BERLinPro* is part of the Helmholtz portfolio topic “Accelerator Research and Development” (ARD), a platform that pools the competencies and resources of the different German research institutions. The platform, intended as a starting point for international collaborations, enhances Germany’s international visibility as a major player in the field of accelerator technologies. Thanks to

the participating centres’ close collaboration, the Helmholtz Association is able to fulfil its mission. Under HZB’s auspices, DESY and the Helmholtz-Zentrum Dresden-Rossendorf – both innovators of large-scale facilities – are also collaborating on the *BERLinPro* project. This collaboration creates a new, internationally unique selling-point for the Helmholtz Association.

THE PARTNERS

Berlin – Germany – The World

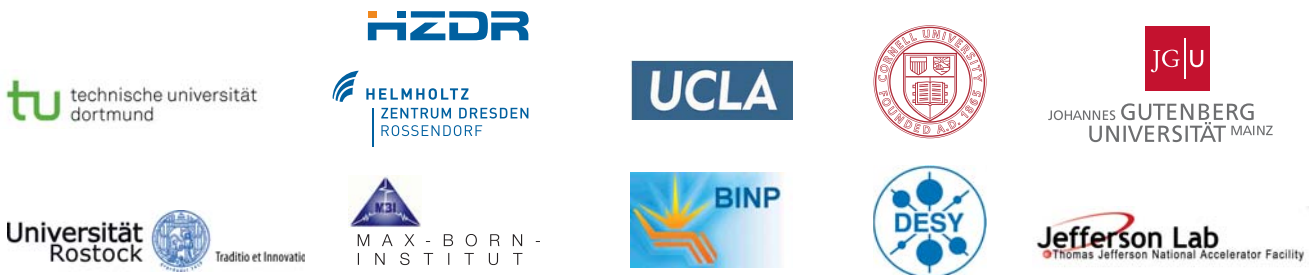
The activities surrounding *BERLinPro* are embedded in an international framework. The pre-accelerator is based on a design originally developed by a collaboration partner at Cornell University, USA. Together with DESY and the Jefferson Lab, HZB is currently working on the superconducting main linac cavities. The Helmholtz-Zentrum Dresden-Rossendorf supports this project by pushing their development of new, superconducting high-frequency electron sources. And together with colleagues from Brookhaven National Laboratory, ASTeC Daresbury, and Universities of Rostock, Dortmund and Mainz, they are all currently part of the *BERLinPro* cooperation agreements, adding to the diversity of global research.

HZB's close neighbour, the Max-Born-Institute, is charged with designing lasers for the photoelectron source, while

the Soltan Institute based in Warsaw, Poland, has been HZB's collaborator in developing superconducting lead photocathodes for the present photoinjector. The University of California-Los Angeles, USA, is collaborating on the ERL beam diagnostics. The „Helmholtz-Russian-Joint-Investigator-Group“ is a collaboration with Russia's Budker Institute Novosibirsk to address the topic of energy recovery Linacs. And last but not least, the *BERLinPro* developers are also partners in the EUCARD- and EuroFEL-projects.

HZB's close ties with Berlin's Humboldt University are strengthened through the Joint Laboratory for Accelerator Physics, which helps consolidate their respective research activities under one roof, while furthering the education of future accelerator physicists.

Not only do all of these various partnerships allow HZB to combine scientific expertise in Germany and Berlin, but it also gives HZB the chance to be an important contributor to the international research scene.



The Machine Advisory Committee

The international scientific community closely follows and evaluates the development of *BERLinPro*. An international „Machine Advisory Committee“ (MAC) meets regularly in Berlin to review the *BERLinPro* project. Germany is represented on the MAC by DESY's Drs. Holger Schlarb and Siegfried Schreiber along with Universität Mainz's Dr. habil. Kurt Aulenbacher. Cornell University's Prof. Dr. Georg Hofstaetter, as well as Jefferson Laboratory's Dr. Andrew Burrill and Committee Chairman Prof. Dr. Geoffrey Krafft represent the United States. Importantly, both Cornell University and Jefferson Lab are heavily involved in ERL development, thus ensuring that the committee is well-aware of the unique challenges posed by ERLs.

Especially noteworthy has been the fact that in less than two years, HZB has managed to produce the first electron beam with a completely superconducting photoelectron source. An excellent high-current electron beam is a prerequisite for all ERL applications. The committee has praised *BERLinPro* as work of „exceptional scientific and technical quality.“ As far as scientific evaluations go, praise does not get any better than this.

THE FACES BEHIND BERLinPro:

THE HEADS OF BERLinPro

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and Humboldt Universität zu Berlin

Prof. Dr. Jens Knobloch

Director, HZB Institute for SRF Science and Technology
and Universität Siegen Director, HZB Institute for SRF
Science and Technology and Universität Siegen



Prof. Dr. Andreas Jankowiak



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