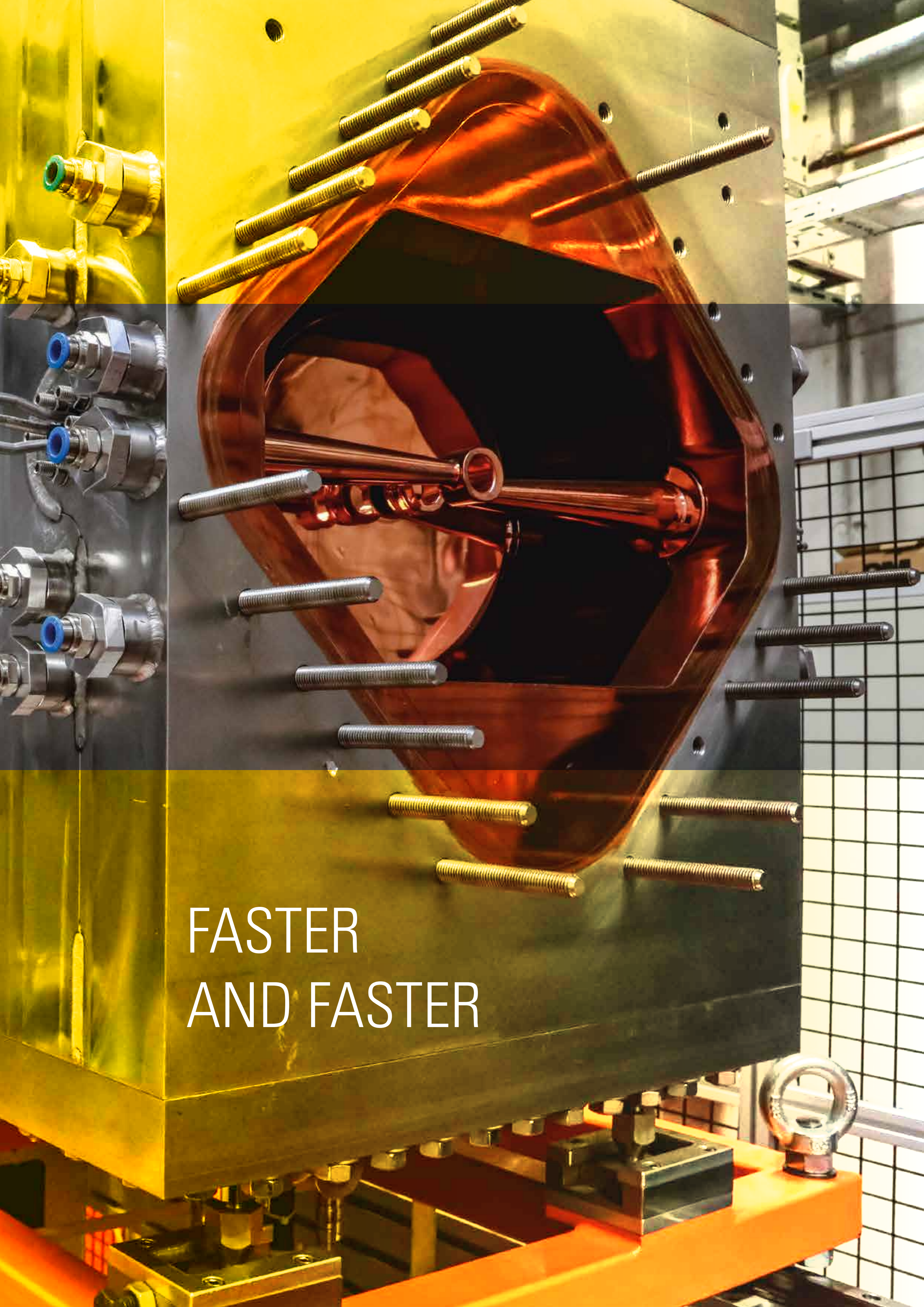

FASTER AND FASTER

The unmoved mover

How the tiniest particles approach the speed of light

By Dirk Eidemüller

Particle accelerators are an indispensable part of the modern research landscape. Some of their main components come from Frankfurt.

They are the unmoved movers of modern science, transfixed atop massive foundations: particle accelerators. After all, they are precision instruments whose components are aligned with each other to within a fraction of a millimetre. All the gigantic magnetic coils and accelerator structures that make up the centrepiece of particle colliders must stay firmly in place during operation. Inside, however, extreme conditions prevail.

An almost perfect vacuum ensures that tiny particles can whizz through the tubes without colliding. Thanks to ingenious electronics, huge electromagnetic forces tug at the particles and accelerate them to the verge of what natural laws allow – namely, almost to the speed of light.

"No particle made of matter can move at the exact speed of light or faster," says Ulrich Ratzinger, professor for accelerator physics at Goethe University. "That's what Albert Einstein's theory of relativity tells us." But you can get closer and closer to this threshold, and then an interesting effect occurs: if you are already close to the speed of light and continue to pump energy into the accelerated particles with the help of electromagnetic fields, their speed hardly increases any further. But their mass increases more and more. In line with Einstein's famous formula that energy is equal to mass times the speed of light squared, particle accelerators can thus convert acceleration energy into particle mass.

Giant stars and Big Bang research

"This allows us to enlarge lightweight particles, such as electrons or protons, to many times the original mass they have in their resting state," explains Ratzinger. This additional mass gives them correspondingly greater momentum when they collide with other particles or hit a target. Researchers then search for new types

Copper and steel colossus: inside the accelerators, electromagnetic fields accelerate the particles between the drift tubes. They are shielded as they fly through these tubes. The field can now change direction and give the particles further thrust as they exit the ring. All inner surfaces are plated with copper to damp the radiofrequency wave as far as possible.

Photo: Uwe Dettmar

of particle or physical effects in the debris of such collisions. But the radiation produced in a particle accelerator can also be used to x-ray materials.

At any rate, modern science is inconceivable without these unmoved movers. Scientists use them not only in their search for elusive dark matter and to measure the properties of elementary particles. With the help of fast particles, it is also possible to reconstruct the processes inside giant stars or produce the ultra-hot plasma from atomic nuclear matter that prevailed in the Universe shortly after the Big Bang. Extremely brilliant x-rays with laser characteristics can be decoupled from particle accelerators like at the European XFEL in Hamburg, which produces the sharpest x-ray pulses in the world and has made Germany a global leader in this field of research. The apparatus there can be used to x-ray new materials, biological samples and chemical processes on the shortest spatial and temporal scales.

Photo: Dieter Fehrenz/GSI/FAIR

FAIR is a new accelerator facility currently under construction at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt. The technology for one of the first two acceleration stages, a linear accelerator for protons, comes from Frankfurt.

"Neutrons don't come off the shelf"

But particle accelerators are also currently being built in two other parts of the country that will facilitate work at the cutting edge of science. Close to Darmstadt, the FAIR accelerator centre (Facility for Antiproton and Ion Research) is near completion. Building on decades of expertise in heavy ion research at GSI in southern Hessen, an international consortium is building a particle accelerator complex capable of answering hundreds of questions from basic and applied research. And in Frankfurt, FRANZ, the "Frankfurt Neutron Source at the Stern-Gerlach-Zentrum", is currently under construction. Although small in comparison to FAIR, thanks to technological innovations it should also allow measurements to be conducted that have so far not been possible in this form.

"With FRANZ, we want to produce high-definition neutron beams with unique beam quality," says Ratzinger. Neutrons are perfect for radiographing materials and complement x-rays very well, but while it is easy to decouple x-rays as electromagnetic radiation from x-ray tubes or from the European XFEL, generating neutron radiation is far more difficult. Neutrons don't come off the shelf: they are found together with protons in atomic nuclei and must first be released from this "cage". Until now, this has mainly been done in research reactors. "But in future, these reactors will be replaced by special particle accelerators like FRANZ, since these can produce high-definition neutron beams that can be controlled with great precision," explains Ratzinger.

ABOUT ULRICH RATZINGER

Uli Ratzinger, born in 1956, studied physics at the Technical University of Munich. He wrote his doctoral thesis on the development of particle accelerator cavities. He joined GSI Darmstadt in 1987, where he is responsible for the design and development of new linear accelerator technology for GSI and CERN. He also contributed to the development of a special type of accelerator for tumour therapy, which was used at Heidelberg Ion Beam Therapy Centre (HIT) and later at other therapy centres. Since 1999, he has concentrated on superconducting accelerator components and especially the new high-current proton linear accelerator at GSI/FAIR. Uli Ratzinger was appointed as professor at Goethe University in 2000 and as Gerald Kucera Laureate Professor for his excellent contribution to accelerator physics in 2009. In 2003, he co-founded Bevatech, a consulting company in the field of linear accelerators.

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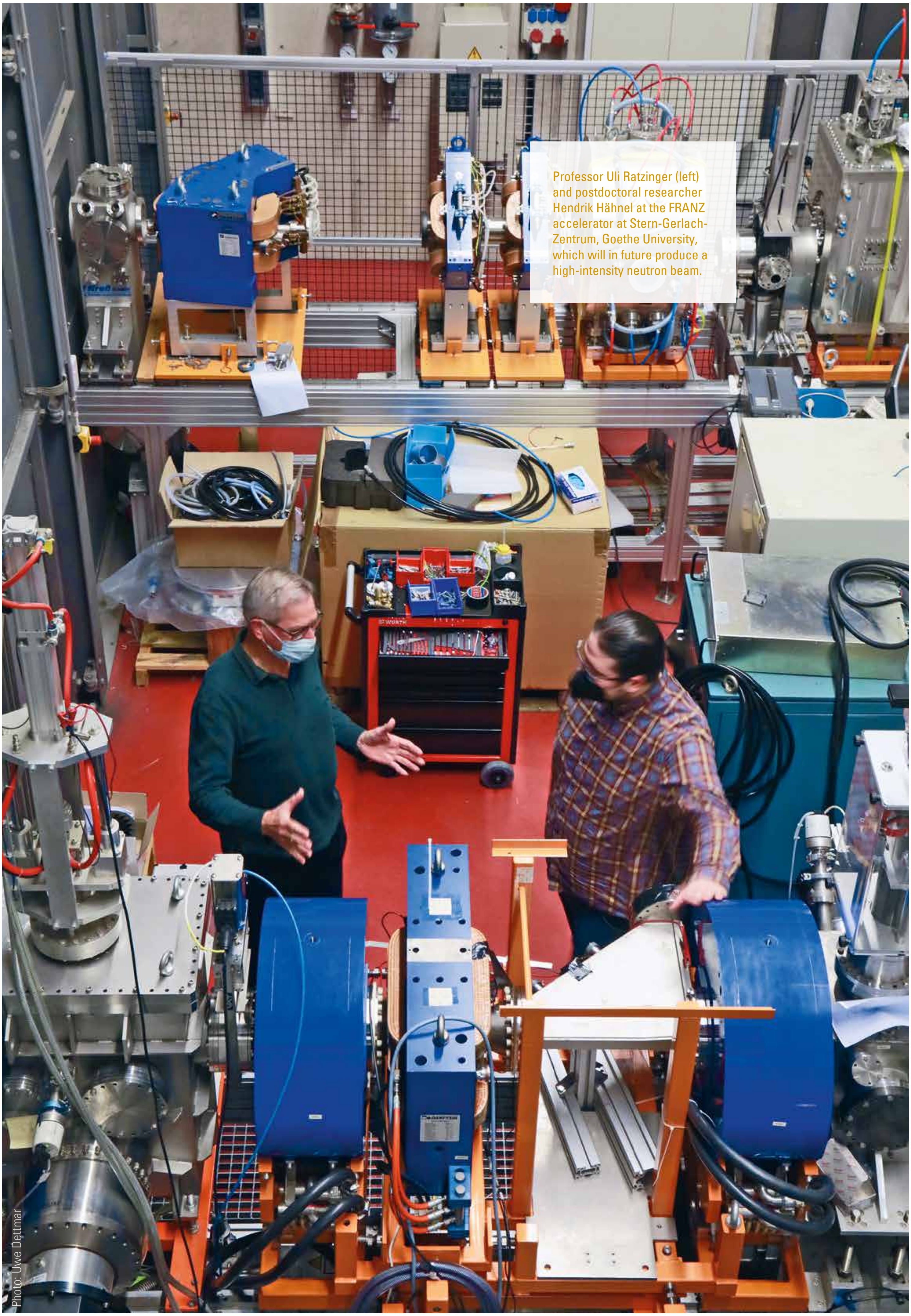

Professor Uli Ratzinger (left) and postdoctoral researcher Hendrik Hähnel at the FRANZ accelerator at Stern-Gerlach-Zentrum, Goethe University, which will in future produce a high-intensity neutron beam.

Photo: Uwe Dettmar

IN A NUTSHELL

- With the help of electromagnetic fields, particle accelerators propel tiny particles almost to the speed of light.
- Scientists at Goethe University are developing concepts for linear accelerators, for example for FRANZ, the university's own neutron accelerator, and for the FAIR ion accelerator in Darmstadt.
- Accelerators are mainly used in basic research. However, at GSI in Darmstadt, for example, a method for cancer treatment based on carbon ion beams was also developed.

Exotic requests

At FRANZ, a linear accelerator will generate 250,000 proton pulses per second, which are then fired at a target. In the process, neutrons are released with each pulse that can be separated according to speed. In this way, neutrons with clearly defined properties are obtained, which on the one hand can help to solve astrophysical questions – such as the fusion of elements in giant stars. On the other hand, the researchers also hope to find new approaches for cancer treatment by allowing the neutrons to react with a boronic substance that docks onto tumours.

"Initially, the specifications expected of FRANZ had us racking our brains quite a bit. The research community expressed rather exotic requests, well beyond conventional accelerator technology," says Ratzinger. This meant that the specialists in Frankfurt not only had to design an extremely fast pulse sequence of 250,000 pulses per second – far greater than any other particle accelerator. FRANZ was also expected to generate a very powerful beam at the same time so that as many neutrons as possible are produced. "To do this, we had to develop new components, such as a compact, high-frequency accelerator for high-current proton beams and fast-switching transverse electric fields that shape the protons flying out of the source into pulses in the course of microseconds."

Space-saving design for FAIR accelerators

While FRANZ is a regional project, FAIR will in future be the most important international facility for heavy ion research. Its main components are the accelerator technology and the particle detectors. In large particle accelerators, coupling two types of accelerators has proved effective: first, a linear accelerator propels the particles up to speed, then ring accelerators – known as synchrotrons – pick up the already fast particle bunches and accelerate them to the highest energy level. FAIR has two ring accelerators: the two heavy ion synchrotrons "SIS18" and "SIS100". The technology for the pre-accelerators comes primarily from Frankfurt.

"We're basing the new FAIR proton linear accelerator on an innovative, compact design that has enabled us to reduce its size by around half in comparison to earlier models," says Ratzinger. This is possible thanks to the clever geometry of the cavities and the electromagnetic fields that oscillate in them, accelerating the particle bunches in the process. This space-saving and energy-efficient design saves not only electricity during operation but also vast quantities of concrete: such a powerful particle accelerator has to be shielded with thick concrete walls so that no dangerous particle radiation leaks out.

Cancer treatment and neutron star research

When FAIR goes into operation in a few years' time, it will be possible to accelerate particles of all sizes, from lightweight protons to heavy elements – and even to produce antiprotons, that is, antimatter particles. "In addition, the experimenters will be able to separate rare, short-lived and exotic atomic nuclei, which are the result of collision experiments, from the particle beam and conduct precision experiments with them," says Ratzinger.

Testing innovative cancer therapies, getting close to the Big Bang, studying matter under extreme astrophysical conditions, exploring the origin of the elements: none of this would be possible without particle accelerators. The unmoved movers unveil to us what's going on in the world's innermost core. ●

THE AUTHOR

Dirk Eidemüller, born in 1975, studied physics (major) and philosophy (minor) in Darmstadt, Heidelberg, Rome and Berlin. He graduated in astroparticle physics and holds a doctoral degree in philosophy of science. He lives in Berlin and works as a freelance author and science journalist.

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