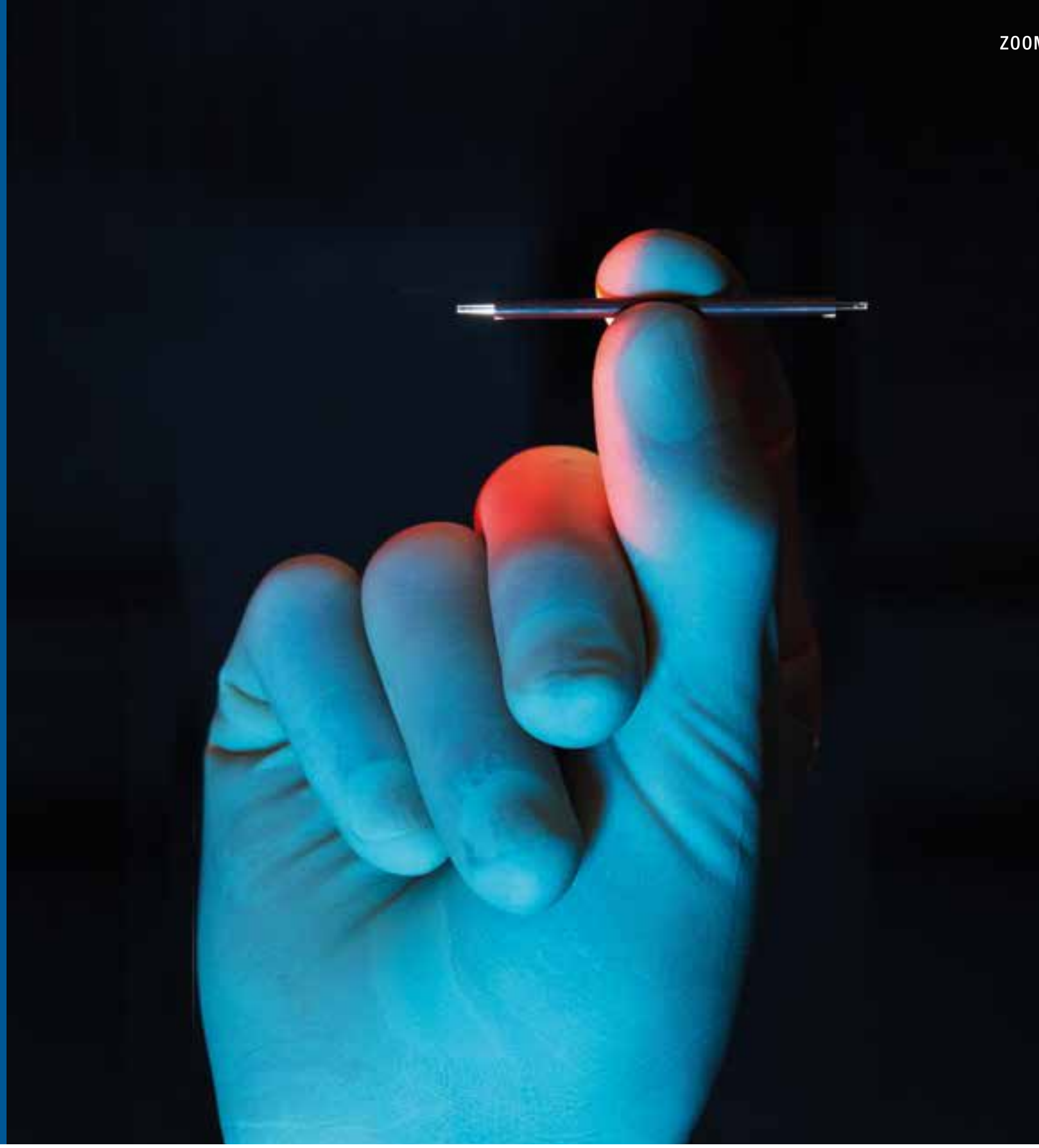


Terahertz accelerator modules fit easily between two fingers.

The terahertz trick

Short wavelength promises accelerators hundreds of times smaller

Franz Kärtner holds up an unremarkable copper tube. It has the same diameter as a ballpoint pen refill, but it's much shorter. "Here you see one of the core components of our terahertz accelerator," explains Kärtner, who is a physicist at the Centre for Free-Electron Laser Science (CFEL), a joint institution of DESY, Universität Hamburg and the Max Planck Society. Kärtner's objective is to build an accelerator that is significantly shorter than today's facilities, but can accelerate electrons to the same energies.

In conventional accelerators, the particles are brought up to speed using radio waves. These have wavelengths in the ten-centimetre region. "Our concept makes use of considerably shorter wavelengths," explains Kärtner, who is a leading scientist at DESY. "Instead of ten centimetres we take one millimetre, that is one hundredth the size." This terahertz radiation can be used to accelerate particles more efficiently. The idea is that much more energy can be transferred to the particles over the same distance.

But generating sufficiently powerful terahertz radiation is not straightforward. In Kärtner's laboratory, this is done on a massive, vibration-damped table. Mounted on the table is a laser that fires intense flashes of light onto

Picture: DESY, Heiner Müller-Elsner

a small crystal. This causes the crystal lattice to emit terahertz waves. A parabolic reflector captures these waves and focuses them on a small copper tube – the actual accelerator. Inside it is another, even smaller tube made of quartz. Within it, the injected terahertz waves give a substantial boost to a bunch of electrons that the researchers guide through the tube.

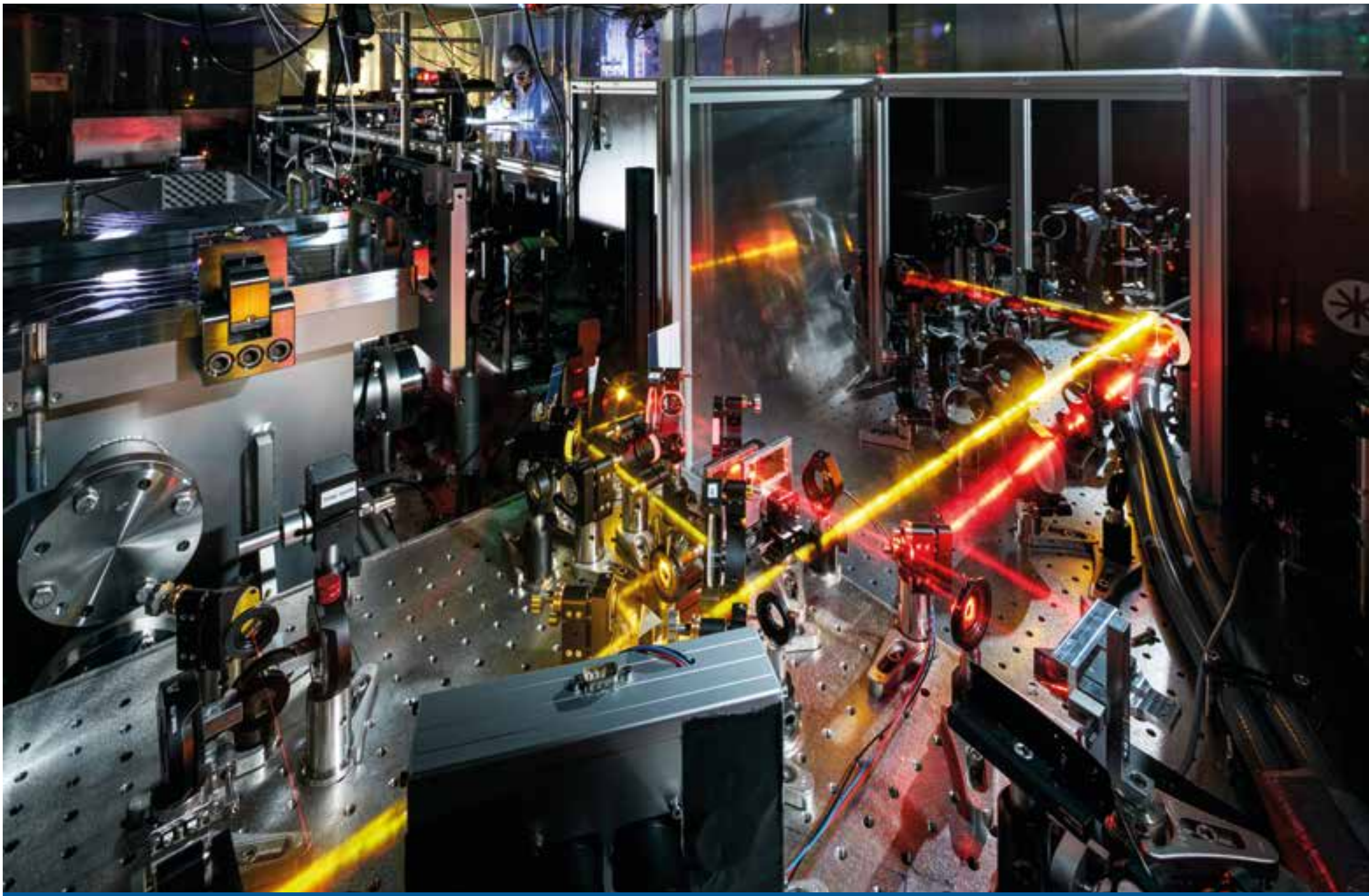
In 2015, the experts at CFEL first succeeded in operating their prototype. At that time, they achieved an accelerating voltage of five megavolts per metre – just about one fifth of the acceleration gradient delivered by the accelerating cavities of the European XFEL X-ray laser. But the feasibility had been proven. By now, the group can generate much more powerful terahertz waves with their equipment and achieves accelerating voltages of up to 70 megavolts per metre – three times that of the European XFEL cavities.

"Our concept makes use of considerably shorter wavelengths"

Franz Kärtner, DESY

Electrons at almost the speed of light

At the moment, Franz Kärtner and his team are building a larger experiment named AXSIS at DESY, which is financed by a Synergy Grant from the European Research Council (ERC). "We want to realise the first X-ray source based on terahertz technology here," explains the physicist. ››



Lasers of various wavelengths play a central role in new accelerator technologies. They can for example be used to generate terahertz waves, which are difficult to produce.

Picture: DESY, Heiner Müller-Elsner, Gesine Born (portrait)

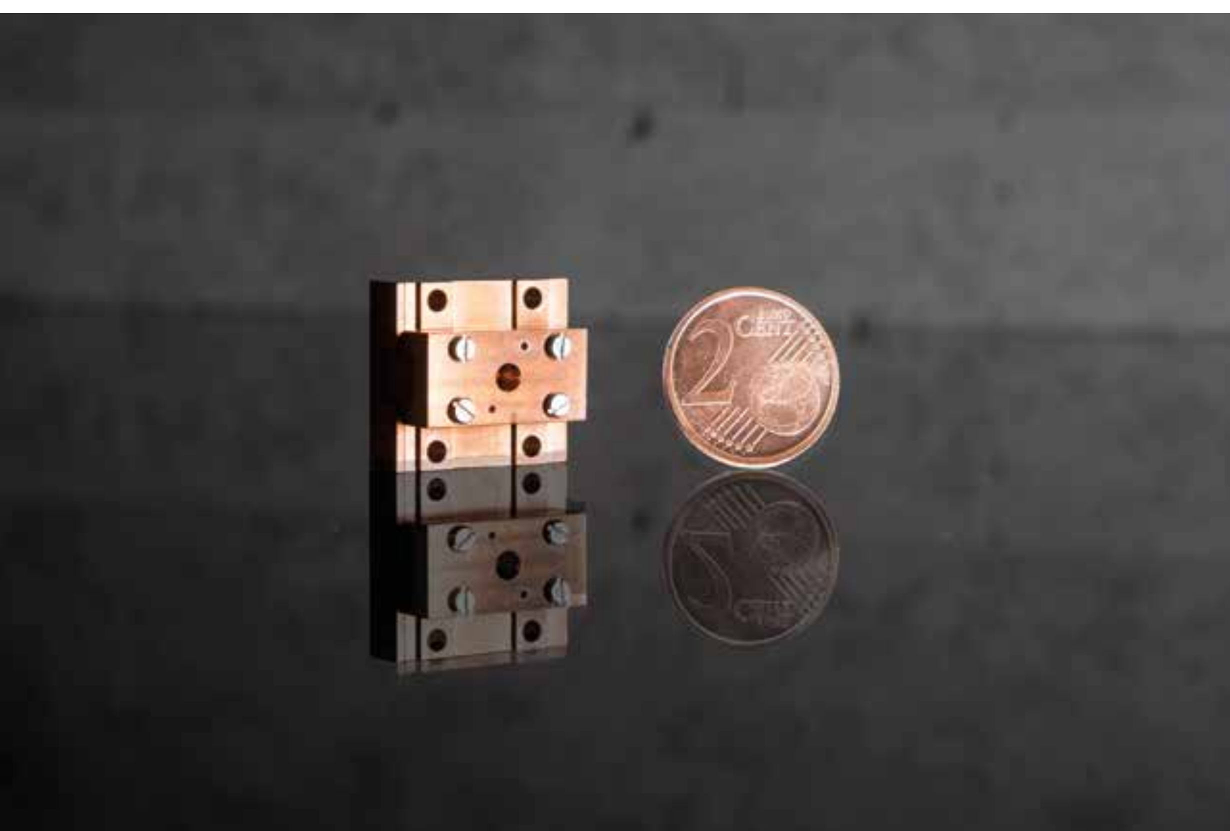
“In principle, it would be possible to shrink a 100-metre-long accelerator down to one metre”

Franz Kärtner, DESY

The plan is to bring the particles to an energy of almost a million electronvolts (MeV) using a terahertz-based electron gun. This means the electrons are travelling at close to the speed of light, which makes it easier to inject them into the main accelerator, the small copper tube. Driven by 1000 ultrapowerful flashes of light per second, the device should accelerate the particles to 20 times their initial energy – to 20 MeV. The researchers then want to direct this high-speed bunch of electrons towards an “optical undulator” – a laser beam that will cause the electrons to sway from side to side in a controlled fashion and so force them to emit intensive X-ray radiation.

But the laser appears to be just one way to generate terahertz waves for future accelerators. This could also be done using gyrotrons – devices in which fast electrons race along helical paths through a magnetic field and emit high-frequency radiation as they do so. The usual application for this type of gyrotron is as a kind of microwave heater for nuclear fusion experiments such as the International Test Reactor (ITER) in Cadarache in the south of France. In the coming years, Kärtner and his colleagues intend to find out whether gyrotrons are also suitable for use as drivers for their accelerator. “It’s possible that terahertz waves can be produced much more efficiently with a gyrotron than with a laser,” says Kärtner. “In principle, we should be able to achieve accelerating voltages of 300 megavolts per metre. Then it would be possible to shrink a 100-metre-long accelerator down to one metre.”

That would open the door to ultracompact X-ray lasers firing a rapid succession of high-precision X-ray flashes, with which it would be possible to study proteins essential for life, for example. A terahertz accelerator would also be of interest as a diagnostic tool for medical applications. As an alternative to the good old X-ray tube, it could provide images with extremely high resolution while lowering the radiation load on the patients at the same time.



Multi-talent: The Segmented Terahertz Electron Accelerator and Manipulator (STEAM) developed by the group of Franz Kärtner is a kind of Swiss Army knife for electron beams. STEAM is powered by terahertz radiation and can accelerate, compress, focus and analyse electron bunches. The experimental device is about the size of a two-cent coin. The active structure in its interior is just a few millimetres in size.

Picture: DESY, Gesine Born