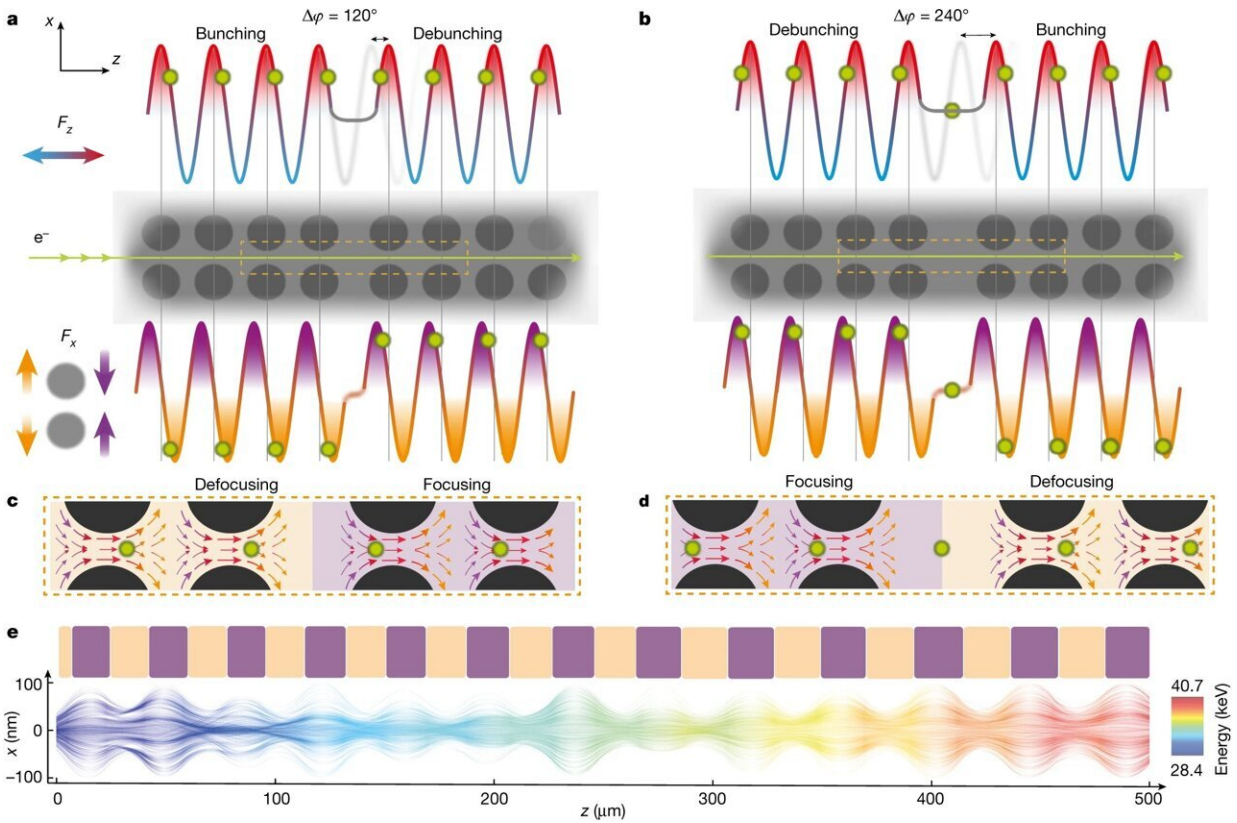


A physics milestone: Miniature particle accelerator works

October 18 2023



Principle of simultaneous acceleration and beam confinement in a nanophotonic structure. **a**, A short, roughly 5- μm -long section of the dual pillar accelerator structure (gray). Laser light incident along the viewing direction generates an optical mode inside of the structure comoving with the electrons (green). Top and bottom: sketches of the synchronous Lorentz force components F_z and F_x acting on a design electron, that is, an electron synchronous with the propagating nearfield mode and initially positioned at a phase of $\varphi_s = 60^\circ$, depicted as a green disk. Before the phase jump, the electron experiences an acceleration force (F_z

positive). At the same time, the transverse forces act in a transversally defocusing way on the electrons (F_x negative for electrons at negative x coordinates, for example, see bottom left). After an abrupt phase jump of $\Delta\varphi = 120^\circ$, the electron enters the same nanophotonic mode in the next macrocell, but is now phase-shifted to $\varphi_s = -60^\circ$ (top right). Also here the electron experiences an acceleration force (positive F_z), but now the transverse forces act in a focusing manner (bottom right; see also **c**). This repeats with every period of the laser field, that is, every 6.45 fs, which is depicted for multiple laser periods as the electron (green disk) propagates through the structure. The simultaneously arising longitudinal bunching and de-bunching is discussed in the main text. **b**, A depiction of a phase jump from a focusing to a defocusing macrocell with $\Delta\varphi = 240^\circ$ (effectively -120°), shifting the design electron from $\varphi_s = -60^\circ$ to $\varphi_s = 60^\circ$. **c,d**, Zoom-in of the relevant regions in **a** and **b**, respectively, with the arrows showing the force field at one instant in time. **e**, Simulated trajectories of electrons as they travel through the accelerator structure while gaining energy (color shows instantaneous energy). The orange and purple blocks above depict the corresponding macrocells that act transversally focusing (purple) and defocusing (orange). Credit: *Nature* (2023). DOI: 10.1038/s41586-023-06602-7

Particle accelerators are crucial tools in a wide variety of areas in industry, research and the medical sector. The space these machines require ranges from a few square meters to large research centers. Using lasers to accelerate electrons within a photonic nanostructure constitutes a microscopic alternative with the potential of generating significantly lower costs and making devices considerably less bulky.

Until now, no substantial energy gains were demonstrated. In other words, it has not been shown that [electrons](#) really have increased in speed significantly. A team of laser physicists at Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) has now succeeded in demonstrating the first nanophotonic electron [accelerator](#)—at the same time as colleagues from Stanford University. The researchers from FAU have now published their findings in the journal *Nature*.

When people hear "particle accelerator," most will probably think of the Large Hadron Collider in Geneva, the approximately 27 kilometer long ring-shaped tunnel which researchers from around the globe used to conduct research into unknown elementary particles. Such huge [particle accelerators](#) are the exception, however. We are more likely to encounter them in other places in our day to day lives, for example in medical imaging procedures or during radiation to treat tumors.

Even then, however, the devices are several meters in size and still rather bulky, with room for improvement in terms of performance. In a bid to improve and decrease the size of existing devices, physicists around the globe are working on dielectric laser acceleration, also known as nanophotonic accelerators. The structures they use are merely 0.5 millimeters in length, and the channel the electrons are accelerated through is only roughly 225 nanometers in width, making these accelerators as small as a computer chip.

Particles are accelerated by [ultrashort laser pulses](#) illuminating the nanostructures. "The dream application would be to place a particle accelerator on an endoscope in order to be able to administer radiotherapy directly at the affected area within the body," explains Dr. Tomáš Chlouba, one of the four lead authors of the recently published paper.

This dream may still be far beyond the grasp of the FAU team from the Chair of Laser Physics led by Prof. Dr. Peter Hommelhoff and consisting of Dr. Tomáš Chlouba, Dr. Roy Shiloh, Stefanie Kraus, Leon Brückner and Julian Litzel, but they have now succeeded in taking a decisive step in the right direction by demonstrating the nanophotonic electron accelerator. "For the first time, we really can speak about a particle accelerator on a chip," says Dr. Roy Shiloh.

Guiding electrons + acceleration = particle

accelerator

Just over two years ago the team made their first major breakthrough: they succeeded in using the alternating phase focusing (APF) method from the early days of acceleration theory to control the flow of electrons in a vacuum channel over long distances. This was the first major step on the way towards building a particle accelerator. Now, all that was needed to gain major amounts of energy was acceleration.

"Using this technique, we have now succeeded not only in guiding electrons but also in accelerating them in these nano-fabricated structures over a length of half a millimeter," explains Stefanie Kraus. While this might not sound like much of an achievement to many, it is a huge success for the field of accelerator physics. "We gained energy of 12 kiloelectron volts. That is a 43 percent gain in energy," explains Leon Brückner.

In order to accelerate the particles over such large distances (when seen from the nano scale), the FAU physicists combined the APF method with specially developed pillar-shaped geometrical structures.

This demonstration is just the beginning, however. Now the aim is to increase the gain in energy and electron current to such an extent that the [particle accelerator](#) on a chip is sufficient for applications in medicine. For this to be the case, the gain in energy would have to be increased by a factor of approximately 100.

"In order to achieve higher electron currents at higher energies at the output of the structure, we will have to expand the structures or place several channels next to each other," Tomáš Chlouba explains the next steps of the FAU laser physicists.

More information: Tomáš Chlouba, Coherent nanophotonic electron

accelerator, *Nature* (2023). DOI: [10.1038/s41586-023-06602-7](https://doi.org/10.1038/s41586-023-06602-7).
www.nature.com/articles/s41586-023-06602-7

Provided by Friedrich–Alexander University Erlangen–Nurnberg

Citation: A physics milestone: Miniature particle accelerator works (2023, October 18) retrieved 30 April 2024 from <https://phys.org/news/2023-10-physics-milestone-miniature-particle.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.