Higher energies for laser-accelerated particles possible

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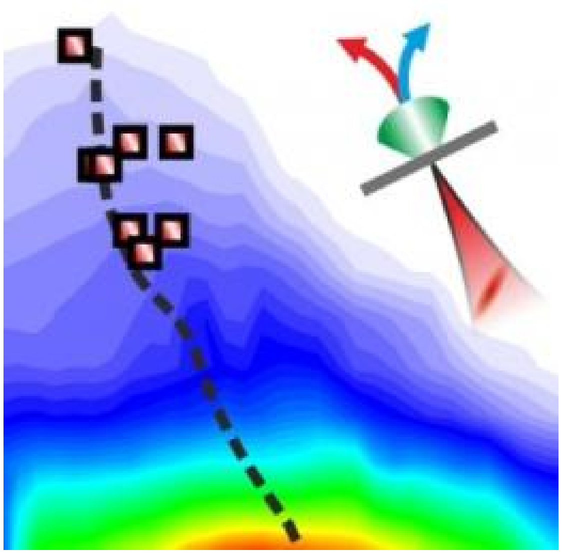
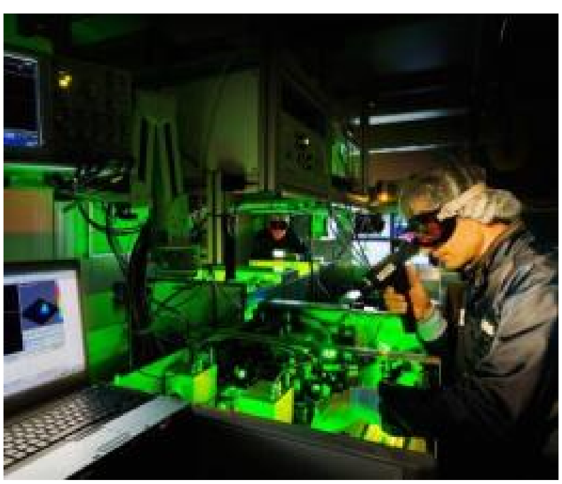


High-performance lasers are very promising and compact proton sources which could be used, for example, in future cancer therapies. With the DRACO laser, HZDR physicists demonstrate for the first time ever that protons are able to absorb energy very efficiently during the first acceleration phase. Credit: Karl Zeil / *Nature Communications*

The use of compact laser accelerators for cancer therapy with charged particles such as protons could become possible in the future if scientists succeed in generating protons with very high energies.

Physicists at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) directed the light of the high power laser DRACO perpendicularly and obliquely onto a thin metal foil; thus, permitting them to demonstrate for the first time that accelerated protons follow the direction of the laser light. By incorporating this new data into a conventional model describing the laser particle acceleration, high proton energies which have not been realized so far might become achievable. The results have been published in the scientific journal *Nature Communications*.

The intense and ultra-short light pulses of the high power laser DRACO can be thought of as disks of about 10 centimeters in diameter and being as thin as a normal sheet of paper. If one of these disks of light is focused onto a thin metal foil, the extreme high electric and magnetic forces will pull negatively charged electrons out of the foil. These electrons will then accelerate positively charged protons away from the foil's surface. To date, many experts have thought that commercially available laser systems would not be suitable for future cancer therapy applications because they have such short laser pulses, and the energy which is achieved by the accelerated protons is correspondingly too low. The results published by the HZDR group demonstrate for the first time that proton energies needed for cancer therapy could, in principle, also be generated from such a short pulse laser. This prospect motivated the Dresden researchers to study the particle acceleration process very closely.



This is the high-intensity laser DRACO at the HZDR. Credit: Jürgen Lösel

New Two-Phase Model for Laser Accelerated Particles

A light pulse coming from the DRACO laser and directed perpendicular onto a thin metal foil accelerates electrons, and thus also protons, perpendicularly to the foil's surface, just like previous models predict. But that is not the case with a tilted laser pulse. If the angle of the thin light disk is slightly tilted with respect to the axis of propagation, something unexpected happens during the first phase of the particle acceleration. The electrons feel the rotation of the light disk and follow the direction in which the light hits the foil. Moreover, protons are accelerated along this direction as well and, in contrast to the electrons, maintain their direction. This novel observation of the directional dependence permits the Dresden physicists to also look directly at the underlying acceleration process.

"During the first acceleration phase, the distance between the electrons and the foil is extremely small. Once the short laser pulse has pushed them through the foil, they immediately swing back again because the foil has a positive charge. That is one reason why we were very surprised to discover that not only the electrons follow the motion of the laser light, but also the protons exhibit this previously unknown directional dependence," notes the doctoral candidate and main author of the current publication, Karl Zeil. He managed to detect another particular feature which only occurs with ultra-short laser pulses: The initial phase is decisive for the entire acceleration process. During the first 30 femtoseconds – that is, one millionth of one billionth of a second, and equal to the length of the laser pulse – the acceleration is very efficient. The short and efficient acceleration phase is followed by a longer expansion phase, during which a uniform and symmetrical plasma cloud is formed. The protons, however, gain so much energy during the first phase which, in turn, makes them so fast that they finally can reach higher energies than conventional models would predict.

Precisely how the fast electrons oscillate around the foil, and thus, accelerate the protons, is investigated by the HZDR scientists also with the help of simulations. Karl Zeil: "Experiments and simulations agree quite well with each other. With the newly obtained data we can now extend the presently existing models. This essentially means that ultra-short pulsed lasers like our DRACO laser could potentially be capable of generating protons with sufficiently high energy so that they can be used in future cancer therapy. That we were successful in obtaining these results is both very pleasing and very motivating."

DRACO Being Expanded, PENELOPE Newly Added

The DRACO laser currently reaches a peak power of 150 terawatts – this translates into the output of all power plants in the world – albeit only for a period of 30 femtoseconds at a time. The laser physicists at the Helmholtz-Zentrum Dresden-Rossendorf want to expand DRACO to 500 terawatts and are currently building a petawatt laser system called PENELOPE. As a modern accelerator technology, particle acceleration with laser light provides considerable advantages when compared to conventional systems: The acceleration distance is much shorter and the costs for such systems are potentially lower. Currently, the OncoRay center, which is jointly supported by the cooperation partners HZDR, University Hospital, and TU Dresden, is building a modern proton therapy facility on the University Hospital's campus. The new facility will be used for cancer research and therapy. For the first time ever, the prototype of a high performance laser will be operated here in addition to a conventional proton accelerator.

More information: K. Zeil u.a., "Direct observation of prompt pre-thermal laser ion sheath acceleration, in: Nature Communications, Volume 3 (2012), Article number 874, DOI: 10.1038/ncomms1883

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