PRESS-RELEASE

Max Planck Institute of Quantum Optics

and

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Playing Billiards with a Laser Beam

A research team led by physicists at LMU Munich reports a significant advance in laser-driven particle acceleration. Using tiny plastic beads as targets, they have produced proton bunches that possess unique features, opening up new opportunities for future studies.

In their experiments, the group fired a powerful laser pulse at a micrometer-sized plastic sphere, blasting a bunch of protons from the target and accelerating them to velocities approaching the speed of light. The resulting velocity distribution is much narrower than that obtained when thin metal foils are used as targets.

Recent years have seen remarkable advances in the development of a new approach to the acceleration of subatomic particles. This strategy makes use of the intense electric fields associated with pulsed, high-energy laser beams to accelerate electrons and protons to 'relativistic' velocities (i.e. speeds approaching that of light). Laser-driven acceleration of protons opens up a new route to the construction of compact particle accelerators. Hitherto, the laser shot has generally been directed at a thin metal foil, generating and accelerating a plasma of free electrons and positively charged ions. Physicists at the Ludwig-Maximilians-Universität (LMU) in Munich have now replaced the foil target by a plastic microsphere with a diameter of one-millionth of a meter. These beads are so tiny that they cannot be stably positioned by mechanical means. Instead, the researchers use an electric field to levitate the target particle. Using a feedback circuit, the levitated bead can be trapped with sufficient precision to ensure that it does not drift off the beam axis. The electromagnetic trap was designed and built in the Department of Medical Physics at LMU.

The experiments were carried out in collaboration with researchers from the Max Planck Institute of Quantum Optics, the Helmholtz-Zentrum in Dresden-Rossendorf, the GSI Helmholtzzentrum für Schwerionenforschung (Centre for Heavy-Ion Research) in Darmstadt, the TU Darmstadt, the TU Dresden, Goethe University in Frankfurt am Main, and the Helmholtz Institute, Jena.

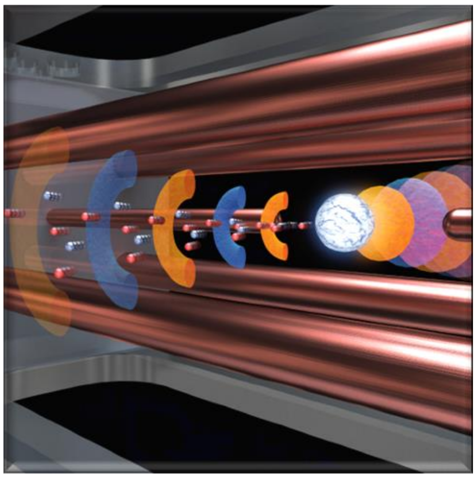

***Figure**: Artist's impression of the laser-plasma interaction: The laser beam approaches the electrodynamic particle trap from the left and impinges on the levitated plastic microsphere, accelerating a bunch of electrons and protons. (Graphic: Marcel Menke)*

Blasting a bunch of protons from such a plastic microsphere requires extremely powerful and efficient laser systems. The PHELIX laser in Darmstadt, which was used in the experiments, has the necessary specifications. It is capable of producing laser pulses that last for 500 femtoseconds (1 femtosecond is equivalent to a millionth of a billionth of a common second), and transport

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150 joules of energy (the amount needed to launch an apple to an altitude of 75 meters).

The laser energy is focused on a region with a diameter comparable to the width of a human hair. The power density achieved is equivalent to the deposition of the total amount of energy generated globally in a single year on an area of 1 cm^2. Thanks to the particular geometry of the microsphere target used in these experiments, the impact of the laser beam produces a plasma whose properties would be virtually impossible to reproduce by bombarding a foil target.

Conventional laser-powered proton acceleration results in proton bunches in which the velocity distribution is exponential, i.e. most of the particles are accelerated to relatively low velocities and very few are ejected from the target at the highest speeds. The proton bunches generated in the new study are very different in this respect: They have a very narrow energy spread – in other words, most of the particles exhibit very similar velocities. This kind of behavior is highly unusual for laser-driven proton beams, and it is of crucial significance for future applications of the new approach.

In parallel with the experimental work, the team also carried out simulations of the dynamics of the proton plasma on the TITAN supercomputer. The results suggest that a typical proton bunch contains approximately 14 percent of the protons present in the original spherical target. This in turn implies that a significant fraction of the plastic sphere is accelerated in a compact and directional fashion under these conditions. Moreover, the simulations also show that only a small proportion of the energy delivered by the laser is actually imparted to the protons, which indicates that there is plenty of room for improvement.

The basic approach is analogous to collisions between billiard balls. “In our experiment, one of the balls is made of light and the other is our tiny levitated target,” explains Peter Hilz, who led the experiments. This novel approach to the generation of proton beams will make experiments feasible which have hitherto been out of reach. “In the coming years, we will concentrate on optimizing the new acceleration process with the help of further simulations and experiments,” Hilz adds.

Potential future applications can be envisaged in fusion research, materials science and the treatment of cancers. The proton bunches generated with the new technique should also be of interest for studies in fundamental physics. For example, they could make it possible to recreate on a laboratory scale states of matter found in the interior of the Sun or in the inner recesses of giant planets such as Jupiter and Saturn. *Thorsten Naeser*

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