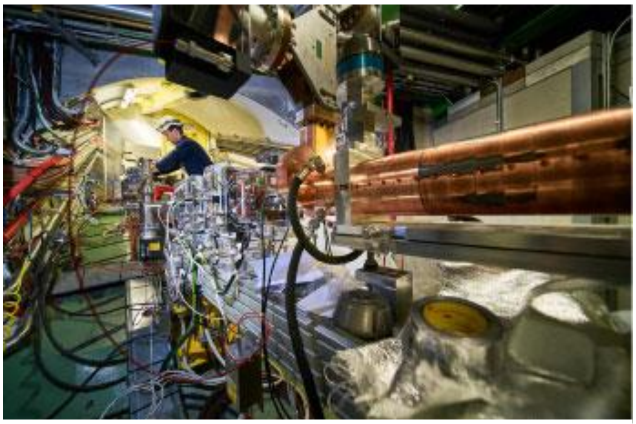
AWAKE experiment at CERN demonstrates for the first time electron acceleration in a plasma wave generated by a proton beam

In an article published today in *Nature*, CERN's AWAKE collaboration reports the first experiment on electron acceleration in plasma waves generated by a proton beam. The acceleration obtained in this first demonstration is already several times larger than that used by conventional technologies currently available for particle accelerators. The use of plasma waves (the so-called wakefields), first proposed in the 1970s, has the potential to drastically reduce the size of particle accelerators.



AWAKE Experience Beam Line (Credit: CERN)

AWAKE, which stands for *Advanced WAKEfield Experiment*, is a demonstration project of a compact electron accelerator at very high energies over short distances. This project involves more than 15 institutions, including Portuguese researchers from Instituto Superior Técnico, from the Group for Lasers and Plasmas of the Institute for Plasmas and Nuclear Fusion.

Accelerating particles at higher energies over shorter distances is crucial to achieving high-energy collisions, used by physicists to investigate the fundamental laws of nature. It is also important in a wide range of medical and industrial applications. Plasma, the fourth state of matter, can be induced by the ionization of a gas – that is, by the ejection of electrons from atoms or gas molecules. In the AWAKE experiment, rubidium is heated and converted into gas, which is then ionized with a laser beam. A proton beam is injected together with the laser pulse, causing the plasma to oscillate in well-defined waves, very much like a ship sailing through the water will leave oscillations in its wake. The AWAKE experiment receives the proton beam of a 400 GeV (a thousand million electron-volt) energy from CERN's Super Proton Synchrotron (SPS), which is the last one in the chain of accelerators that delivers protons to the LHC. An electron beam (known as a "probe beam") is injected with a slight angle into the oscillating plasma, and gets accelerated as it surfs the plasma waves.

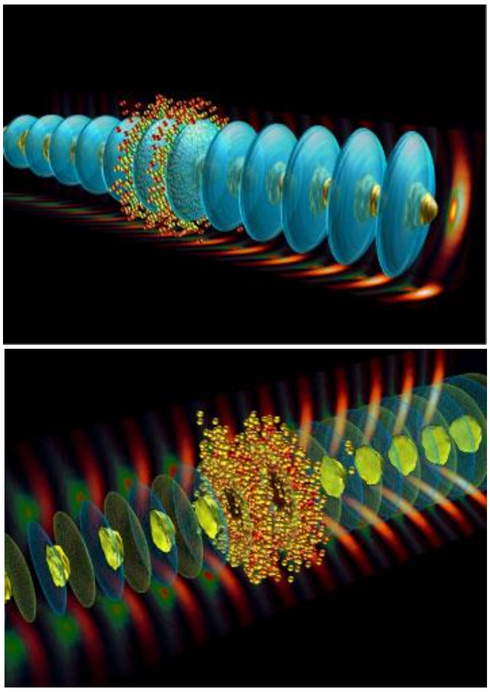
On May 26, the AWAKE collaboration successfully accelerated the electron beam for the first time. Electrons from AWAKE were injected at relatively low energies of about 19 MeV (millions of electron-volt), "surfed" the plasma wave and were accelerated by a factor of about 100 to an energy of almost 2 GeV million electron-volt in just 10 meters.

Previous experiments on plasma wave acceleration have used electrons or lasers to generate the wake, whereas AWAKE is the first to use protons. "Proton beams penetrate deeper into the plasma than electron beams and lasers," says Allen Caldwell, spokesman for the AWAKE collaboration. "Therefore, plasma accelerators that use protons to generate waves can accelerate electrons at significantly longer distances, allowing these electrons to reach higher energies."

"By accelerating electrons to 2 GeV in just 10 meters, AWAKE has shown that it can reach an average gradient of about 200 MV/m (millions of volts per meter)," said AWAKE technical coordinator and project leader at CERN, Edda Gschwendtner. As a comparison, the conventional technologies to be considered for the next generation of electron accelerators will allow achieving gradients in the range of 30 to 100 MV/m.

In the next steps, aiming at demonstrating average acceleration gradients of 1000 MV/m, longer sustained acceleration distances will be explored and the intensity and quality of accelerated beams will be optimized, two important factors for the experiments of particle physics.
"The experimental results confirm the numerical simulations and the theory developed at IST since 2012," said Luís Oliveira e Silva, coordinator of the team of Instituto Superior Técnico (IST) involved in this study. This team also includes Jorge Vieira and Nelson Lopes, senior researchers at IST, Ricardo Fonseca, ISCTE-IUL professor, and Mariana Moreira and Anton Helm, PhD students at IST. In the next phase of the collaboration, the IST team will contribute with theoretical and numerical simulation studies, and will develop a new technology to obtain plasma columns with length in excess of 10 meters, which are essential to take full advantage of the acceleration potential.

AWAKE has made rapid progress since its inception. The experiment's kick-off took place at a meeting at IST, Lisbon in 2012. The plasma cell was installed at CERN in early 2016. A few months later, the first proton bundles were injected into the plasma cell to test the experimental device, and the proton-generated plasma waves were observed for the first time by the end of 2016.



Numeric simulation of the AWAKE experiment (Credit: Jorge Vieira/IST)

High resolution images with numeric simulations performed by the IST team:
https://golp2.tecnico.ulisboa.pt/nextcloud/index.php/s/OuIDsbChIll4zWW

Videos:
Animation (2018) – Credit CERN: https://cernbox.cern.ch/index.php/s/FAAtA1eJ0GRnu9z
The animation illustrates how the Advanced WAKEfield Experiment (AWAKE) demonstrated electron acceleration in plasma waves generated by a proton beam.

In this experiment, a 10-meter plasma cell is filled with rubidium gas (pink), supplied by two vessels, and controlled by heating the samples. A proton beam (red line) from Super Proton Synchrotron (SPS) from CERN enters the plasma cell simultaneously with a laser beam (green). Rubidium gas is transformed by the laser into a different state of matter, called plasma (yellow), and the proton long beam is divided into a group of shorter short beams, which create accelerated plasma waves. Electron groups ("witness beam", blue circles) are injected, captured by plasma waves and accelerated to high energies, such as a surfer catching a wave and surfing. This technique may offer a new way to build small-energy high-energy particle accelerators.

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