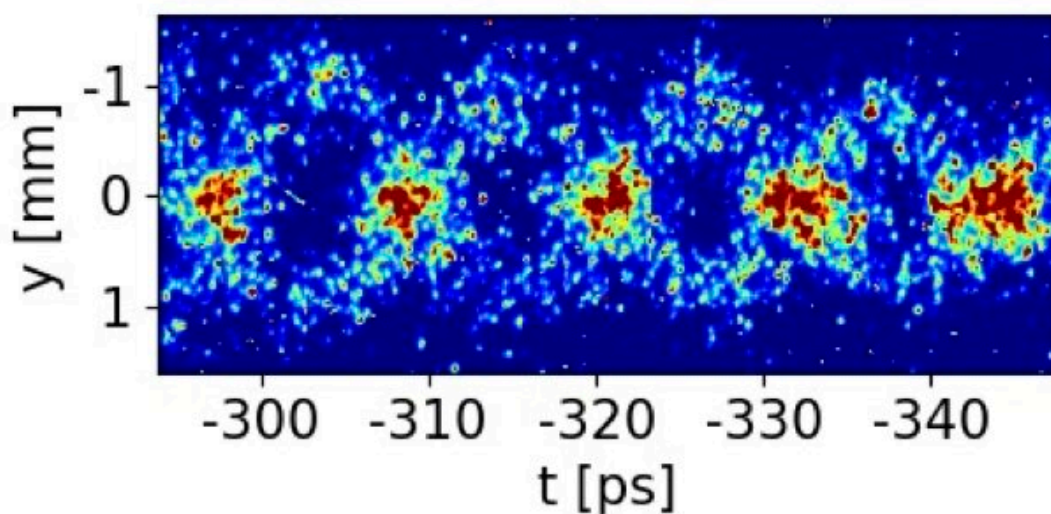


# AWAKE sows seeds of controlled particle acceleration using plasma wakefields

July 18 2022, by Thomas Hortalá

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The figure shows the sum of ten consecutive time-resolved images of the self-modulated proton bunch. The bunch travels from left to right. The timing of the modulation is determined by the preceding electron bunch and it is reproducible from event to event. Credit: CERN

From the tunnel that hosted the now-retired CERN Neutrinos to Gran Sasso (CNGS) facility, AWAKE (Advanced Wakefield Experiment) is looking to revolutionize the field of particle acceleration. The

23-institute-strong collaboration aims to introduce a viable and more efficient alternative to traditional radiofrequency acceleration—with charged particles (in this case, electrons) "surfing" on the waves of a plasma field (or "wakefield") generated by a short, intense proton bunch fired through the plasma.

While [plasma](#) wakefields have been shown to produce acceleration gradients up to 1000 times superior to those achieved with radiofrequency cavities, their use in [high-energy](#) and particle physics experiments has been limited by the impractical nature of current techniques, which require the juxtaposition of several plasma sources to achieve high energies. AWAKE, on the other hand, is the first experiment to investigate the use of protons, rather than lasers or electron beams, to drive the plasma.

To create the appropriate wakefields in the plasma for efficient electron acceleration, the long [proton](#) beam extracted towards AWAKE from the CERN Super Proton Synchrotron (SPS) needs to be broken up into smaller bunches in a process known as modulation. In a *Physical Review Letters* paper published on 6 July, the collaboration showed how such a modulation of the proton beam can be controlled by seeding the process with relativistic [electrons](#)—a crucial step towards a workable wakefield-based accelerator.

To grasp the concept of seeding, it is necessary to delve into the technology behind AWAKE. The proton beam from the SPS is injected into a vapor source containing rubidium, which is transformed into a plasma (a state of ionized gas) by a laser pulse that precedes the proton bunch. A short electron bunch can then be injected into the proton wake to be accelerated to high energy. For the electrons to ride the waves of the plasma efficiently, the length of the proton bunch needs to equal the plasma wavelength. Luckily, the long proton beam from the SPS automatically breaks up into such small bunches when propagating

through the plasma (it "self-modulates"), which is what allowed AWAKE to demonstrate the first acceleration of electrons using this technique in 2018.

"To preserve the reproducibility of the entire modulated proton beam, and thereby its ability to accelerate electrons, we devised a technique to control exactly when the modulation begins: we seed it with an initial electron bunch, different from the one that is targeted for acceleration. By injecting this bunch several hundreds of picoseconds before the protons enter the plasma, the front of the proton beam modulates in sync, creating a regular wakefield whose phase can be precisely measured," explains Livio Verra, a physicist in the Lepton Accelerators and Facilities (ABP-LAF) section in the Beams department and the first author of the paper. Injection of the electron bunch whose acceleration the experiment is targeting can then be timed perfectly. The acceleration therefore becomes sustainable and controlled, producing an unparalleled overall gradient.

Edda Gschwendtner, the AWAKE project leader at CERN, looks to the future with optimism: "The ultimate success of the wakefield technology developed by AWAKE rests on the feasibility of seeding the proton bunch self-modulation. With this milestone now achieved, the collaboration is ready to tackle our next challenges, starting with the commissioning of a new plasma source."

This source, which is being developed by the Max Planck Institute in Munich, Germany, will generate a plasma with two regions of different density (and, therefore, of different temperature), which will further increase the overall acceleration gradient with respect to that achieved so far. The introduction of a new plasma source is only one aspect of the rich program of studies to be performed during AWAKE's second physics run.

CERN's Long Shutdown 3 will see the dismantling of the last remaining components of the CNGS facility. AWAKE plans to make the most of this opportunity, using the freed space for the next phases of the experiment. These phases will focus on accelerating electrons to high energy while preserving the [beam](#) quality, a prerequisite for future applications in particle physics.

In parallel, the collaboration will continue to develop scalable plasma source technologies, such as discharge and helicon plasma cells, which are key to increasing the final energy reach. Once these technologies have been validated, and controlled electron acceleration has been demonstrated, it will open the door to future high-energy applications, such as fixed-target experiments searching for dark matter.

**More information:** L. Verra et al, Controlled Growth of the Self-Modulation of a Relativistic Proton Bunch in Plasma, *Physical Review Letters* (2022). [DOI: 10.1103/PhysRevLett.129.024802](https://doi.org/10.1103/PhysRevLett.129.024802)

Provided by CERN

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