Surfatron: catch the wave of accelerators

The science of Surfatron

Surfatron was designed with the intention of demonstrating the concept of wakefield acceleration, a novel technique of particle acceleration, in which electrons are pushed forward by the electrostatic forces that arise between regions of different density in a plasma. This process is commonly depicted as electrons riding a wave in a similar way to surfers riding waves on the sea.

Particle accelerators were invented in the 1920s. They use the oscillating electric fields contained in a meters-long evacuated metallic cavity called a radiofrequency (RF) cavity. The accelerating gradient of RF cavities is limited by electrical arcing inside the cavity, which occurs when the field is too intense. Therefore, longer accelerating distances are required to achieve higher energies. Since their invention, accelerators have grown in size, complexity, and applications; however, the underlying technology – RF cavities – remains practically unchanged.

Currently, there are over 50 000 particle accelerators around the world.[1] Many of them are used in hospitals for cancer treatment, but they also find applications in manufacturing, security, and research. The world's largest accelerator is the Large Hadron Collider (LHC), near Geneva (Switzerland), which is a circular machine with a circumference of 27 km (figure 1).[2]

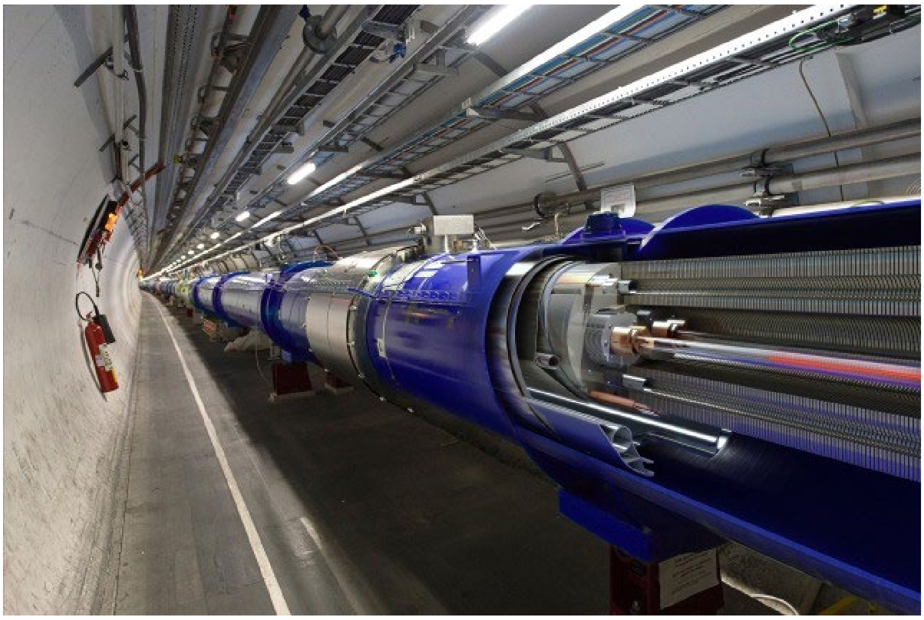

Figure 1: Inside the huge circular tunnel of the LHC
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Particle colliders are reaching their practical limits in terms of size and cost. Moreover, as particle accelerators find more applications in a wider range of areas, there is strong demand for cheaper and more compact accelerators.

Scientists are looking for alternative acceleration techniques that might lead to more affordable machines than those based on conventional technologies, and one such technique is wakefield acceleration.[3]

In a wakefield accelerator, a high-power laser pulse or particle beam is fired into a chamber filled with plasma (a gas of ionised atoms). As the bullet-like laser or particle beam travels through the plasma, it creates ripples or density fluctuations in its wake (figure 2). The density fluctuations – or plasma waves – are then used to accelerate a bunch of electrons, which are injected into the cavity immediately after the driving beam.

The strong electric fields that arise in the plasma waves allow the electrons to gain very high energies over a very short distance, thus providing the smaller and potentially cheaper alternative to conventional particle accelerators that scientists are looking for.

A number of international projects, such as the European consortium EuPRAXIA[4] and the AWAKE experiment at CERN,[5] are developing wakefield acceleration technology that could revolutionise the future of accelerators.

Researchers working on these projects are trying to find the optimum conditions to accelerate the particles. Just like in Surfatron, they can control the amplitude, wavelength, and frequency of the plasma waves by varying the density of the plasma and the energy of the laser or particle beam. They must also inject electrons into the chamber at the right time and with the right energy to catch the accelerating plasma waves, so they look into ways to synchronize the electron beam with the laser or particle beams that drive the plasma waves.

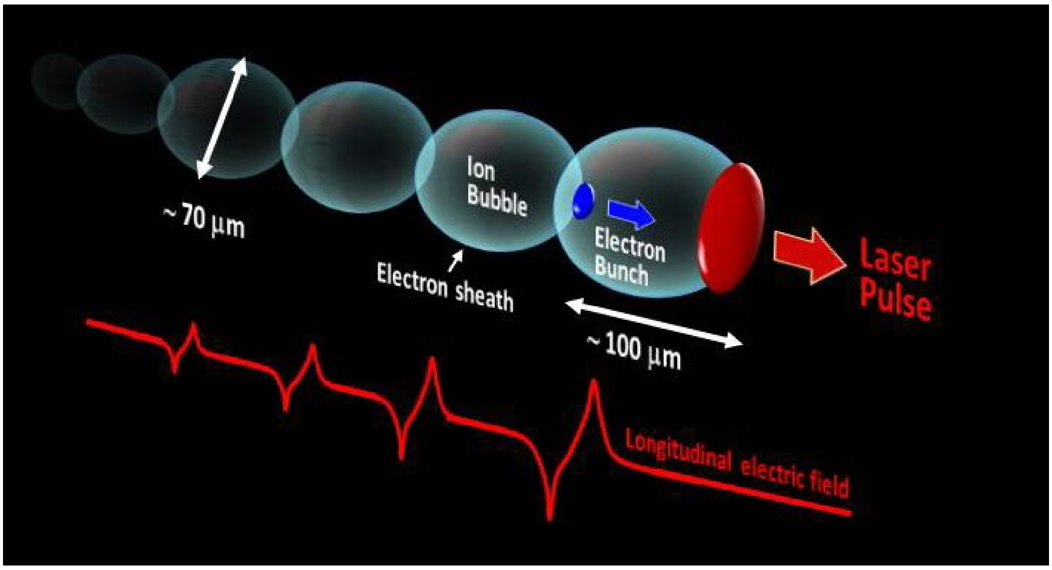

Figure 2: A laser pulse travelling through a gas of ionized atoms creates a wake of plasma waves that can be used to accelerate electrons to a very high energy.
Image courtesy of Ricardo Torres

Differences between Surfatron and real accelerators

Like any analogy, Surfatron has limitations in its representation of the physics of accelerators. The most fundamental difference is that the force acting on the ball in Surfatron is gravity, whereas, in a particle accelerator, it is an electric field.

In a particle accelerator, in principle, the more intense the electric field is, the higher the acceleration. In Surfatron, the acceleration depends on the steepness of the slope, which is determined by the wave amplitude relative to the wavelength. If the amplitude-to-wavelength ratio is too high, the ball will experience more vertical than horizontal acceleration; if it is too small, the ball will not be accelerated at all. Therefore, the optimum amplitude is that which, for a given wavelength, sets the slope at 45°.

Another important difference is that Surfatron only deals with one particle – the ball – whereas real accelerators deal with bunches of charged particles that repeal each other and have a dynamics of their own. Indeed, some of the most important aspects to consider in a particle accelerator – beam charge, energy distribution, transverse and longitudinal profile, emittance, etc. – have to do with the multiparticle nature of the beams.

References

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