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Hope Kindled For Table-Top Accelerators

By MALCOLM W. BROWNE

SINCE 1993, when Congress canceled construction of a $10 billion particle smasher that would have girdled most of a Texas county, prospects have virtually vanished for building still larger machines -- accelerators that might glimpse new levels of organization within the building blocks of matter.

Aware that conventional accelerators may have reached their practical limits of size and cost, physicists dream of developing new ways to boost the energies of the subnuclear projectiles that accelerators use to probe the domain of the ultra-small. The goal is to build cheap table-top accelerators that are able to shoot electrons or protons (or their antimatter counterparts) at the energies achieved by huge and expensive conventional accelerators.

No miniature machine can yet challenge the tried-and-true techniques embodied in the largest present-day accelerators, one of which, the Large Electron-Positron (LEP) collider, is 17 miles in circumference and spans the border between France and Switzerland.

Conventional machines like LEP boost particles to nearly the speed of light by surfing the particles on radio waves as the waves speed through magnetic tunnels.

But recent developments in accelerator technology have kindled hopes that machines only a few yards long may one day accelerate particles to energies far higher than is possible with conventional accelerators of reasonable size.

If the small-scale results of recent experiments can be scaled up, it will be possible for a one-yard-long accelerator to boost electrons to the same energy as that achieved by the two-mile-long Stanford Linear Accelerator in California, said Dr. Donald P. Umstadter of the University of Michigan at Ann Arbor.

Among the goals of future accelerators will be the search for a "Higgs field," a theoretical field extending throughout the universe, which by interacting with fundamental particles is believed to give matter its mass. Another object will be the quest for "supersymmetry," a hypothesized system of equivalence that would allow theorists to unite the force of gravity with the other forces of nature.

In a recent issue of the journal Physical Review Letters, Dr. Umstadter and his colleagues at the Center for Ultrafast Optical Science, a research group at the University of Michigan supported by the National Science Foundation, described a theoretical method for accelerating electrons using a pair of laser beams of enormous power.

If some extremely difficult problems of scaling can be solved, he said in an interview, "we could produce a machine that would accelerate electrons to one trillion electron-volts over a distance of only about 10 meters," or about 33 feet.

His group has already produced a beam of electrons with an energy of 10 million electron-volts by firing a short pulse from a powerful laser into a low-pressure gas. "A 10-million-electron-volt accelerator usually takes up a large room," he said in an interview. "We achieved this acceleration over a distance less than one millimeter.

"If these acceleration gradients are what we think they are, and if we can extrapolate them to very high energies, we could presumably produce the same energy achieved by the two-mile-long Stanford Linear Collider, and do it over a distance of about one yard."

Many high energy physicists are less sanguine.

Dr. Burton Richter, director of the Stanford Linear Accelerator Center and the recipient of a Nobel Prize for particle research, described Dr. Umstadter's work as "very interesting." But "it's very early in the development of this kind of thing," he said. "I think a lot more theory has to be done, as well as some more experiments."

Dr. Richter said he doubted that the technique Dr. Umstadter's group is developing could achieve a greater energy than about 100 million electron-volts in a single stage. (That energy is enormous compared with the energies of high-energy laboratory and hospital X-ray machines, but it is trivial compared with the energy the Stanford machine imparts to electrons, some 50 billion electron-volts.)

To reach or exceed the energies of the largest present-day particle accelerators, devices like those described by Dr. Umstadter would have to be connected in series, so that the particles accelerated by the first stage would undergo further acceleration in successive stages. The biggest problem, Dr. Richter and other physicists say, would be in meshing the particles with the rhythm of acceleration as they pass from one stage to the next.

Dr. Umstadter's method of acceleration exploits some novel properties of a very high-power laser invented by Dr. Gerard Mourou, director of the Center for Ultrafast Optical Science. The laser system produces pulses of light that pass through an optical system that squeezes relatively long pulses into ultra-short pulses, each only a few trillionths of a second long.

Compressed into this tiny period of time, the peak power of the laser reaches about one trillion electron-volts. When a pulse of this power is shot into a chamber containing argon gas, Dr. Umstadter reports, the laser strips atoms of their electrons and creates a wave within the resulting plasma gas that races along at nearly the speed of light. Trailing behind it is an energy wave called a "wake field." The wake field captures electrons from the gas and surfs them up to energies of millions of electron-volts. The resulting electron beam has exactly the same cross-section shape as the laser pulse that created it.

One of the problems solved by using a very high-power laser, Dr. Umstadter said, is the inadvertent spreading and weakening of an electron beam during its initial acceleration. Electrons, which carry negative charges, tend to repel each other, and as a beam of them spreads out, fewer electrons are available for collision experiments. But once a beam of electrons has been boosted to an energy of a few million electron-volts, it creates a magnetic field that holds the beam together.

Dr. Umstadter sees laser wake-field acceleration as the possible basis for a new generation of "injectors," the accelerators that bring particles up to energies at which they can be further accelerated by machines of conventional type.

"The trick is to get the electrons up to a speed at which they can be synchronized with the radio-frequency wave of a high-energy accelerator," he said. "It's like a surfer trying to catch a wave. If he just sits there on his board, the wave will go right over him. So he paddles along to get up to the speed of the wave, and from that point on, he can start to gain energy from the wave."

In a variation of this idea, Dr. Umstadter has designed what he believes will be a greatly improved machine, in which a second laser pulse is shot into the gas at right angles to the first pulse. In this way, loose electrons are given a preliminary boost to facilitate their capture and acceleration by the wake field.

Dr. Chandrashekhar Joshi at the University of California at Los Angeles, a leader in the development of novel methods for accelerating particles, believes that laser acceleration shows great promise up to a point.

"My personal view, based on experiments we have conducted here, is that a billion-electron-volt electron accelerator based on a pulsed laser is feasible in the next five years," he said. However, the possibility of combining such machines in series to achieve the energies needed by particle physicists "is completely unproven and may not be feasible," he said.

Physicists are concerned that novel devices like Dr. Umstadter's should not drain money from the Large Hadron Collider, being built with United States support in Europe. But Dr. Umstadter said:

"We're not in competition with the big conventional accelerators. The kind of acceleration we're developing is complementary to conventional radio-frequency acceleration."

He said the biggest users of future laser accelerators might not be research physicists, but rather manufacturers and hospitals. High-energy electron beams fired at targets made of heavy metals like tungsten generate X-rays, and X-ray pulses produced by electrons from one of the new laser accelerators would be short enough and powerful enough to probe lightning-fast chemical processes like photosynthesis, which sustains green plants.

"Electron accelerators are already everywhere," Dr. Umstadter said. "The picture tubes of TV sets contain electron accelerators. There are 10,000 linear accelerators with energies of millions of electron-volts in use by hospitals for radiation therapy, by industry for photolithography and in many other applications. Even if laser accelerators never achieve the energies needed by particle physicists, they are assured of a niche in industry and medicine."

Diagram: "Catching the Wave" In a new theoretical design for a small particle accelerator, a very high-power laser beam sent through a tube of gas strips atoms of their electrons and creates a wave within the plasma. Trailing behind is an energy wave called a wake field, which captures electrons from the gas and drives them up to energies of million of electron-volts. The beam of accelerated electrons creates a magnetic field that holds the beam together. Diagram illustrates the new design and a table compares the size of the University of Michigan linear accelerator with the large electron-positron and the Stanford linear accelerator. (Source: Dr. Donald P. Umstadter/University of Michigan) (pg. C9)