THE MACHINES

The energy spiral

As particle physicists probe deeper and deeper, the size of their tools—and the cost—climbs

by Ann Ewing

Energies of the atom smashers that nuclear physicists use to probe the infinitesimal world of the atom's core continue to rise, as they have ever since the first man-made accelerator went into operation in 1932.

The energy of a nuclear particle is measured in electron volts, a unit that has nothing to do with the negatively charged carrier of electricity, the electron. An electron volt is the energy given any charged elementary particle by an electric potential of one volt. A single molecule of air at normal temperature moves around with an average kinetic energy of one-fortieth of an electron volt. A molecule on the sun's surface, where the temperature is some 6,000 degrees centigrade, has an energy of about one-half an electron volt.

But in particle accelerators, man can achieve much higher energies. Early atom smashers generated particles having a million electron volts; scientists now measure energies in the billions and tens of billions; they hope soon to be in the range of hundreds of billions.

Proton Accelerators

	Status	Energy (Bev)
CERN		
1. Geneva	1959 in use	28
2. (Geneva)	Study (1977)	(300)
France		
3. Saclay	1958 in use	3
4. (Saclay)	Study (1973)	(45)
Japan		
5. (Tokyo)	Design (1973)	(42)
Netherlands		
6. Delft	Con. (19??)	(1)
USSR		
7. Dubna	1957 in use	10
8. Moscow	1967 in use	1
9. Moscow	1961 in use	7
10. (Moscow)	Study (19??)	(1000)
11. Serpukhov	1967 test	70
UK		
12. Birmingham	1953 in use	1
13. Rutherford	1963 in use	7
USA		
14. Argonne	1963 in use	12.7
15. Brookhaven	1952 ret.	3
16. Brookhaven	1960 in use	33
17. (Brookhaven)	Study (1980)	(1000)
18. Lawrence	1954 in use	6.2
19. Lawrence	Design (1972)	(1.4)
20. NAL, Weston	Design (1972)	(200-500)
21. Pin-Penn	1963 in use	3
West Germany		
22. (Karlsruhe)	Study (19??)	(40)

Oak Rdige National Laboratory

Before year's end, the world's largest particle accelerator—at Serpukhov in the U.S.S.R.—will be speeding protons to energies of 70 billion electron volts, more than doubling the power of the 33 Bev machine operated since 1960 at Brookhaven National Laboratory on Long Island, New York.

Definite plans, however, are being made both by the U.S. and a consortium of European nations to build accelerators having energies, respectively, of 200 and 300 Bev. The range of the U.S. 200 Bev, scheduled to be built at Weston, Ill., could be increased to 400 Bev, making it the world's largest, at some future date (SN: 9/23).

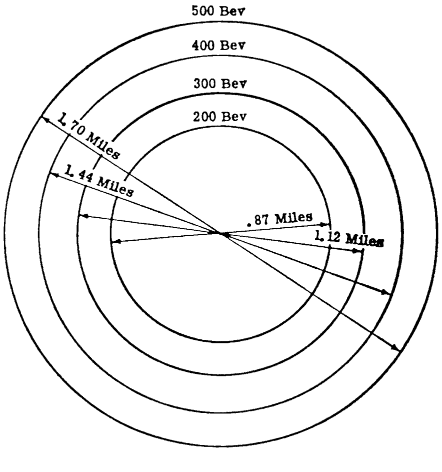
When the location was finally selected as Weston, high energy physicists and accelerator builders had a rare chance to take another look at what had once been firm plans for a machine in the Bev range.

After months of hard study, they came up with a bonus for the future. Within the $300 million budget set by Congress, its designers could build the accelerator at its planned energy and intensity, yet give it the capability of going to 400 Bev, or perhaps even higher, by raising the diameter of the track around which the protons will be accelerated to two kilometers.

The proposal for building such a machine will be made formally to the Atomic Energy Commission by Oct. 15, but it must then pass many budgetary hurdles in both the executive and legislative branches. Scientists hope the bonus they offer in doubled energy will carry the plan.

How this development will affect the plans of the consortium of European nations to build the 300 Bev is not known. Until the results of the Weston study were revealed, the Europeans would have been ahead of the U.S. in putting their machine into operation. Their design was settled, but financing and site location remained thorny problems.

The U.S., on the other hand, had a site selected and financing available, but was without detailed plans. It still is without detailed plans, since the energy goal has changed. But the European group may now want to change its design for the 300 Bev, taking advantage of the simpler construction for the ring developed under the aegis of the National Accelerator Laboratory, which will operate the 200 Bev.



Lawrence Radiation Lab

Ring diameters for various energies.

Even though designs for the 200-400 Bev and the 300 Bev still have to be made firm, high energy physicists around the world are looking forward to the next generation of particle accelerators. They would like to see a machine with an energy of 1,000 Bev, and tentative plans for this range have been drawn by scientists in both the U.S. and the U.S.S.R.

Although the European group, known as CERN II, says it is stretching the limits of today's technology to build a 300 Bev accelerator, many experts doubt the contention. One U.S. scientist declares the difference between building a 300 Bev machine and one of 800 or 1,000 Bev to be the same as the difference between building a Ford Falcon or a Lincoln Continental. The technique is known—it's the care and precision that count.

Also in the future, but probably not as far away as the 1,000 Bev, is the possibility of using superconducting magnets either to guide or focus, or both, the particle beam, even to turn it around (see p. 332). A four-inch superconducting cylindrical chamber, a cavity surrounded by liquid helium, was operated about two years ago (SN: 1/8/66), and scientists around the world are now trying to better that length. The role of the cavity is to trap as much as possible of the input microwave radiation and make it available to accelerate electrons.

Another idea scientists would like to see become a reality is the use of oppositely directed charged particle beams, or storage rings as they are called. Research institutes in the Soviet Union, the U.S., Italy and other countries have carried out theoretical and experimental studies of the idea, which would greatly increase the energy of interaction of particles—two beams of particles having an energy of 25 Bev would collide at the equivalent of some 1,000 Bev.

The drawback is that only limited kinds of experiments could be carried out with such beams.

Meanwhile, in the lower energies, but still in the tens of billions of electron volts, three countries are considering proton accelerators in the 40 to 45 Bev range, with their chances of funding an open question. Japan aims at 42 Bev, France at 45 and West Germany at 40.

Although scientists see justification for the Japanese machine because of Japan's geographical isolation and its need to build a sound base in high energy nuclear physics, many question the wisdom of spending money on the French and West German accelerators, already outclassed by the Russian 70 Bev even before they are out of the design stage.

All of these machines accelerate protons, but in the range above one billion electron volts there is also a whole host of large instruments, mainly for electrons, but at least one for neutrons—Canada's Intense Neutron Generator—and one that could be adjusted for any nuclei ranging from hydrogen to uranium—the Omnitron at the University of California.

Electron Accelerators

	Status	Energy (Bev)
Germany		
1. Bonn	1967 in use	2.3
2. Hamburg	1964 in use	6.25
Italy		
3. Frascati	1959 in use	1.1
Japan		
4. Tokyo	1961 in use	1.3
Sweden		
5. Lund	1960 in use	1.2
USSR		
6. Yerevan	1967 test	6
7. Tomsk	1964 in use	1.3
UK		
8. Daresbury	1966 in use	4
USA		
9. Cambridge	1962 in use	6.28
10. Cal Tech	1952 in use	1.5
11. Cornell	1964 in use	2.1
12. Cornell	1967 test	10

Oak Ridge National Laboratory

Virtually all proton accelerators are circular, as are the high energy electron machines. However, there are some, notably the two-mile LINAC at Stanford University, in a straight line.

Scientists now estimate that, for large accelerators, the cost is about $2 million per billion electron volts.

Whether straight or circular, all accelerators operate generically in the same way. The particles are injected into an evacuated tube, sped along by the application of external energy at short intervals, focused into a tight beam by magnets, then hurled at a target to see what nuclear debris results. From such nuclear footprints scientists have learned much (but never enough) about the structure of matter.

To observe subatomic particles, physicists use the scattering of radiation. X-rays and gamma rays, actually different names for a photon of light, or quantum, gave scientists their first method for checking on the reactions taking place within atomic nuclei, long before man-made accelerators were built. Now they use beams of particles generated to carefully controlled energies.

When nuclear particles are used as light to examine fine details of nuclei, their wavelength is of utmost importance—that of the bombarding particle must be sufficiently short to show structural detail.

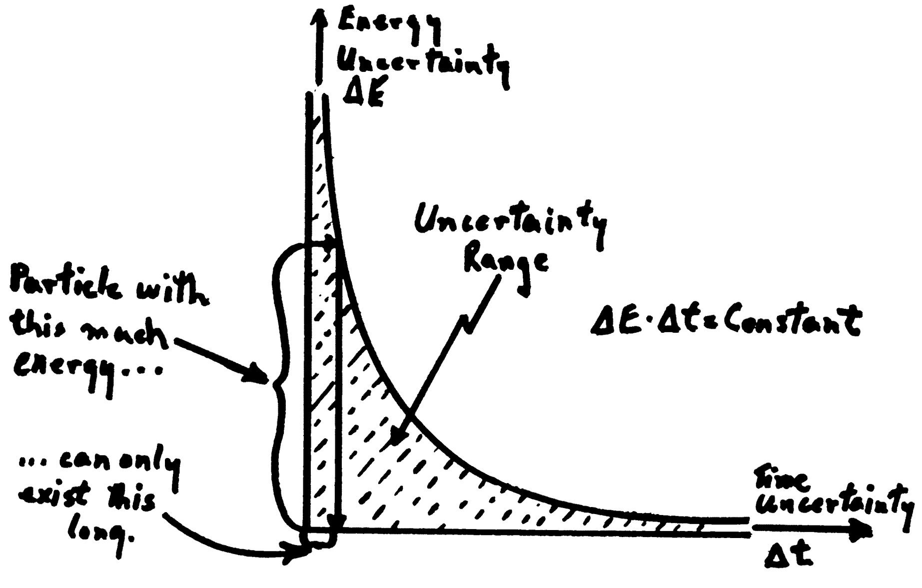
The higher the energy, the shorter the wavelength; that is why machines of higher energy are needed to unlock the basic secrets of the structure of matter. Scattering enters because nuclear particles cannot be seen directly, but their existence and properties can be deduced from the way the incident radiation, the bombarding particles, is scattered by the target nuclei.

Scattering is a general term given to the collisions between two or more particles. There are two kinds: elastic and inelastic.

In elastic scattering, the particles react somewhat like billiard balls, ricocheting off each other but leaving the point of interaction with the same overall energy of motion. In inelastic scattering, one or more of the particles absorbs some of the incident energy, either raising it to a higher energy state or forming an entirely new particle. Energy has been changed into mass.

The more massive the particle being created, the higher the price tag, both in terms of energy and money.

◆



Meson creation: energy conservation can be broken if lifetime is short.

THE THEORY

Plethora of particles

Theorists look to higher energies for clues in their search for simplicity

by Carl Behrens

At a recent Washington, D.C. meeting of the American Physical Society, Dr. Murray Gell-Mann spoke before a huge crowd of scientists. Using complicated mathematics he described his efforts in past months to simplify and organize his theoretical picture of the world of elementary particles.

"It's not as simple as we hoped it might be," he concluded. "We'll have to change the picture and try again."

Theoretical physics has never been simple, but some stages are more puzzling than others. Right now, physicists are faced with an uncomfortable amount of information, with no clear way of fitting it all together in a simple pattern.

Most of this information has come from experiments with high energy accelerators. And the common belief among high energy physicists is that