Leapin' Leptons

"Tomorrow, tomorrow, tomorrow." Like the girl in the famous red dress, physicists are always looking ahead. In their case to more energetic experimental equipment. But they have to talk to Daddy Warbucks too.

BY DIETRICK E. THOMSEN

Faster than a speeding bullet a flying electron meets a positron coming equally fast from the opposite direction. It's a bird, it's a plane, it's superphysics. At least that's how it seems. In recent years physicists have become more and more enamored of the storage rings and colliding beam apparatus that produce electron-positron collisions. And there's good reason. The experiments they do are clean, relatively easy to sort out if frequently surprising, and economical in getting energy into what physicists want to get it into.

An electron-positron collision is a matter-antimatter interaction, an annihilation. Annihilation means that opposites come together and cancel, turning each other into a blob of energy, a virtual photon, that can and does become anything it has enough energy to become. It can turn into almost any particle, provided it has an amount of energy equivalent to the mass of that particle (or to a pair where the rules require production in pairs). The limit to the variety possible is the maximum energy of the apparatus.

Naturally physicists are in a rush to get electron-positron machines of higher and higher energy. In western Europe the rush is a flat-out race, possibly because up to now it has had a strong German push behind it. To give them their official acronymic designations — nobody remembers what the acronyms stand for — the series began with DORIS at the DESY laboratory near Hamburg. It now has PETRA, and, if a dozen governments can agree, by the mid 1980s it may have LEP, for which design is already underway. The maximum center-of-mass energy, that is, the energy available to the blob, is 10 billion electron-volts (10 GeV) for DORIS, 38 GeV for PETRA and will be something between 70 and 100 GeV for LEP.

LEP has not yet been officially authorized, and its proponents may not succeed in persuading enough governments, especially if there is bad feeling between the soft currency countries and the hard currency countries, but the spirit that comes across is more enthusiastic than the depression and pettifogging 10 years ago that nearly prevented construction of what is now the Super Proton Synchrotron at the international CERN laboratory in Geneva. The European Committee on Future Accelerators, a group that has no diplomatic status but plenty of prestige in physics, recommended LEP as Europe's next high-energy physics venture. (The other serious proposals are to multiply the energy limit of accelerators that strike protons against fixed targets or to build high-energy proton-proton colliding beams.) CERN, which is Europe's biggest particle physics laboratory, has done a preliminary design study and has hosted a design workshop (held at Les Houches in France). Already a fight has broken out between CERN and DESY over where LEP should be (SN: 10/21/78, p. 278).

A report on the latest developments in CERN COURIER was entitled "A Giant LEP for Mankind (with apologies to Neil Armstrong)." For mankind indeed. It may well be mankind's only venture of this sort. The United States government has chosen the option of the proton-proton storage rings, and shows little interest in duplicating LEP. Nobody seems very interested in increasing the energy of fixed-target accelerators right now.

In this multiple choice test the Europeans seem to believe that they have chosen the most versatile instrument. From the track record of lesser-energy electron-positron machines they may be correct. A section of American physicists agrees with them, and some are advocating an American LEP anyhow. (No matter how generous the Europeans may be with visiting privileges, the home team always has the advantage of living nearby and thus being more easily able to supervise experiments that can run for half a decade. And when something isn't yours, you don't treat it the way you would if you had it at home.)

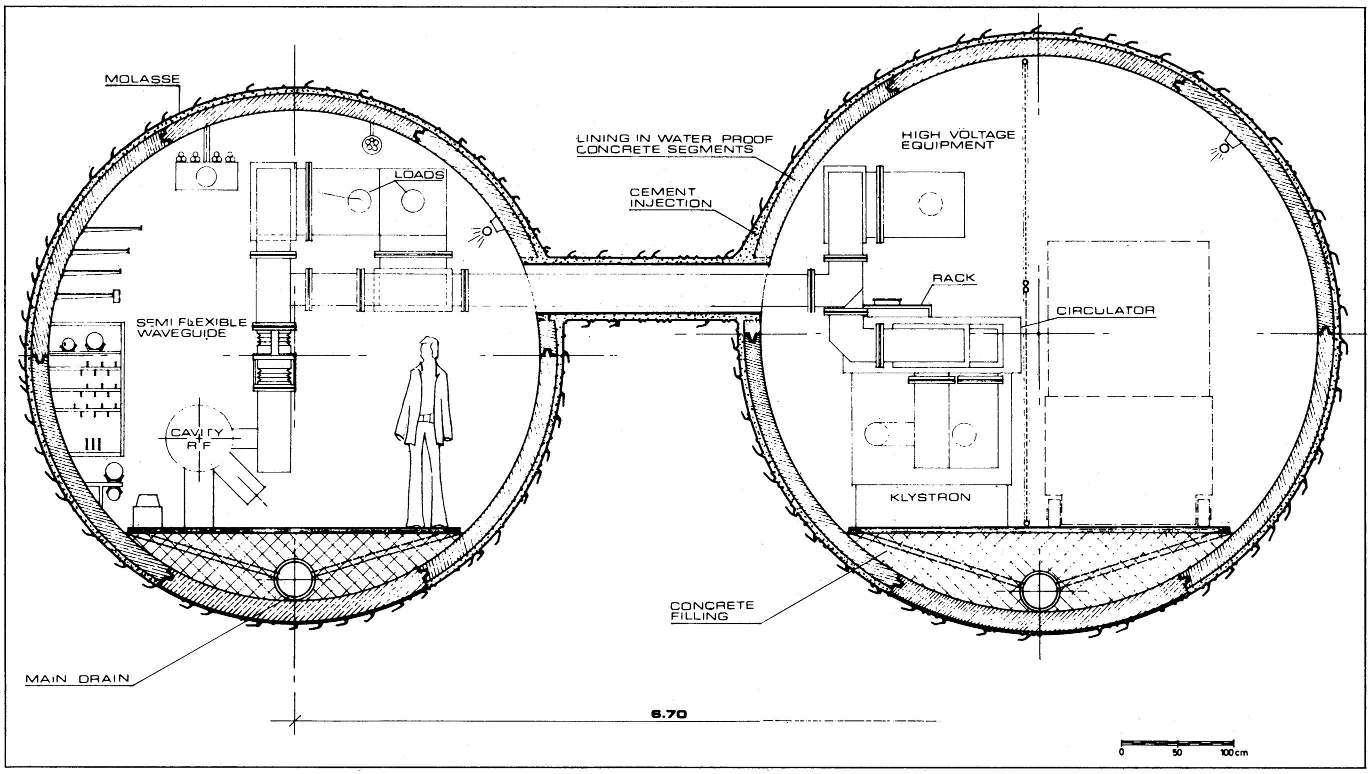
Speed seems essential in these matters. Physics is moving very fast, and it seems to be coming in from all directions to a unified view of the structure and behavior of subatomic particles. Pieces of theory that were built around different parts of the subject seem to be coming together. At the moment the theoretical garment looks more like a patchwork quilt than a seamless robe, but some of the raveled edges are being knit together here and there. One such knitting expedition occurred in the summer of 1978, and it is a good illustration of how the design of the LEP sort of apparatus operates in a tension between very general principles of trying to be all things to all predictable users and trying to take advantage of the latest breaks.

The example concerns an experiment that many physicists say more or less confirmed a theoretical approach that unifies two categories of force, electromagnetism and the weak interaction. Physics recognizes four categories of force: gravitation, electromagnetism, the weak interaction and the strong interaction. Each has its characteristic strength, range and a particular group of particles or larger bodies it affects. To derive a single theory of force, a unified field theory, that would give a united description of all four categories, explaining their differences and exposing their interconnections, is a desire that goes back generations among theoretical physicists. In the last decade the latest mathematical physics has been used to construct a theory that unites electromagnetism and the weak interaction. Electrons and other members of the class of particles called leptons are particularly useful for studying this piece of theory, because they are subject to the weak interaction and to electromagnetism (some of them) but not to the strong interaction, which would swamp the other two if it operated.

The experiment that has convinced many physicists that these theorists are on the right track was done at the Stanford Linear Accelerator Center in California and reported last summer (SN: 7/8/78, p. 21). It used polarized electrons to confirm the existence of a weak-interaction effect that only this theory predicts. Polarized electrons have their spins all in one direction. This sets up an asymmetry between left and right. Weak-interaction effects tend to discriminate between left- and right-handed polarizations; electromagnetic ones do not. So polarization can be used to distinguish the effects of the two interactions where they are mixed.

The Stanford results were published in June 1978. The LEP design study is dated Aug. 22, 1978, and contains an appendix proposing polarized electrons and positrons in LEP. Such a proposal has obviously been under discussion for a long time, but the success of the Stanford experiment means that polarized electrons will become a means that a lot of experimenters will want to use to explore other aspects of the connection. The success indicates that polarized electrons will open the avenues of exploration that physicists hoped they would.

And so we come to the Siberian Snake under the Swiss grass (or maybe the North Saxon grass). The snake is an arrangement of magnets proposed by Ya. S. Derbenev and A. M. Kondratenko to maintain polarization of the particles in the rings. (Motions around circles through magnetic



CERN

LEP *is planned as a double tunnel forming a rough circle 7 or 8 kilometers across. At 8 locations there will be electron-positron collisions and space for the experimental equipment that surrounds the collision points.*

fields tend to depolarize an initially polarized beam.) But if the snake is put in, a lot of complicated arrangements will have to be made, and, most important, one of the eight planned experimental areas will be taken up by the snake. This reduces the number of experiments that can be done at once, and it will squeeze people who want to do things that don't necessarily need polarization.

One of these is the study of quantum chromodynamics. Quantum chromodynamics is the science of the force that animates quarks and holds them together. It is the basic manifestation of the strong interaction. The division of subatomic particles into leptons (the electron and its relatives) and hadrons (the proton, the neutron and their relatives) is the most fundamental from a structural and dynamic point of view. Leptons are believed to be simple unstructured bodies. Hadrons show evidence of an internal structure that is believed to be made up of the famous quarks. It is now thought that there are six varieties (the technical term is "flavors") of quark that go into the various hadronic structures. Experimental evidence for the existence of five of them is now in hand. If indications for the sixth are not found before LEP comes on line, it could find it.

But more important is a systematic study of the various kinds of particles made by different combinations of quarks in an attempt to see how quarks fit together and move around and what is the behavior of the force that animates them and makes them stick together inside the particles they form. Many of the particles involved are very massive (up to ten times the proton's mass now and no one betting how much higher the mass of a single particle might go). It takes a lot of energy to produce them in copious numbers for observation.

Of course every physics laboratory with higher-energy equipment, whatever its type or style, is and will be studying quantum chromodynamics, but LEP's proponents feel their machine has a great advantage in the precision and cleanliness of its particle-producing reaction, and the achievements in this department of lower-energy electron-positron colliding beams tend to support them.

Another of the unifying pieces to be studied is a model, called after its originators the Glashow-Iliopoulos-Maiani model, that proposes a parallelism and a link between leptons and quarks. Both leptons and quarks are seen as structureless elemental bodies. The two classes are linked: The number of massive leptons that exist limits the possible number of quark flavors. At the moment three massive leptons are known: the electron, the muon and the tau. If that is all the massive leptons there are, then quark flavors are limited to six. But there could be more massive leptons. They are limited by the number of possible neutrinos. (Neutrinos are leptons with zero mass.) There should be one neutrino for each massive lepton. At the moment two are known, one for the electron and one for the muon. One for the tau is believed to exist on the basis of the tau's existence. If there are more neutrinos, greater numbers on up the line are possible. There are cosmological arguments that put a limit on the number of kinds of neutrino that can exist. Checking into the existence of that limit and whether or not it has already been reached is an important field for high-energy research.

Finally, there are the intermediate vector bosons, or W and Z particles. These are very important to the unified field theory because they are supposed to be the carriers or embodiment of the weak interaction forces. If there is a weak interaction between two particles, that means they have exchanged W's or Z's. The existence of these particles has never been directly demonstrated. The main reason, physicists are now beginning to think, is that they are very massive. It may take as much as 85 GeV of energy to materialize them. If so, they will only be found where that is available. A 100-GeV LEP might do it.

Of course all this is reckoning without the hosts. The European governments have not yet agreed to build LEP. Their Science Ministers and Foreign Office officials have yet to sit down and work out a treaty for it or an additional protocol to the existing CERN treaty. Even when everyone agrees on the goal, negotiations can be tricky, and there can be many a slip of the pen twixt design study and ground breaking. Politics or budget considerations could intrude on questions of design or siting. The physicists are arguing between CERN and Hamburg on grounds of physics and laboratory logistics. Politicians may have other reasons for suggestions — it has happened on previous projects — and the price of building LEP might be putting it in Narvik or Ballymena. ☐