detector that should be running this fall at Savannah River. They will be studying $\bar{\nu}_e + p \rightarrow n + e^+$, measuring the positron (that is, the $\bar{\nu}_e$) spectrum and moving the detector over the range 12–35 meters from the reactor core.

The Laue–Langevin experiment started running last November and will end this summer. The group, consisting of Felix Boehm, J. F. Cavaignac, D. H. Koang and B. Vignon (Institut des Sciences Nucleaires, Grenoble) and Franz von Feilitzsch and Rudolf Mossbauer (Technical University, Munich), also measured the neutrino-induced reaction on the proton. Their detector, placed 8.7 meters from the core, was a proton-rich scintillator (375 liters) that acted simultaneously as target, positron detector and neutron moderator. He^3 wire chambers detect neutrons in coincidence with positrons. Their signal-to-noise ratio was 1.5 and the event rate 1.5/hour.

Boehm told us they compared their positron spectrum with the theoretical spectra based on calculations of Davis and his collaborators and of Avignone and his collaborators. The Laue–Langevin experiment does not show evidence for neutrino oscillations if compared with the Davis spectrum, but at this time Boehm was not willing to quantify his statement. If there were full mixing, he said, their experiment sets a limit on $\Delta = m_i^2 - m_j^2$ of about 0.2 $(eV)^2$. However, if partial mixing is assumed, the limit on Δ is larger. In addition, in a few weeks the Laue–Langevin experimenters hope to have an on-line measurement of the actual electron spectrum from the reactor, which should resolve the discrepancy between the calculated spectra.[6,7]

This fall, Boehm told us, the Caltech and Munich experimenters will collaborate with a team from the Swiss Institute of Nuclear Research. The equipment will be moved to a 2700-MW power reactor at Gosgen, Switzerland and will make measurements at 38 and 65 meters, where the experiment will be sensitive to values of Δ as small as 0.03 $(eV)^2$.

The Soviet experiment at ITEP on the end point of the tritium beta-decay spectrum was first reported on at the Neutrino 76 conference in Aachen. At that time the group said they had an upper limit of 33 eV on the $\bar{\nu}_e$ mass. Tritium is useful for a neutrino-mass search because of all suitable beta decays, it has the smallest-energy electrons coming out. The mass difference between H^3 and He^3 is very small (18 keV), but one is interested in neutrino masses (about 30 eV) that are comparable to ionization energies.

Recently the ITEP group, consisting of V. A. Lyubimov, E. G. Novikov, V. Z. Nozik, E. F. Tretyakov and V. S. Kosik, submitted a paper to *Yadernaya Fizika* in which they reported results from five years of experiments. The source was valine ($C_5H_{11}NO_2$) containing 18% tritium; its thickness was about two micrograms/cm^2. The group used a beta spectrometer with a rotation angle of 720°. They estimate they had a rather high resolution (about 45 eV at the end of the tritium beta spectrum) and low background (0.03–0.1 counts per second).

After doing a χ^2 minimization for each of 16 samples, the group found a mean value for the mass of ν_e of (34.3 ± 4) eV. To check this value, they did a Monte Carlo simulation, and then discarded unlikely values. They also considered other sources of imitation of nonzero mass and took into account effects from the valine molecules and the atomic level structures of H^3 and He^{3+}. Their final value for the electron neutrino mass (which they still consider to be preliminary) is that it is in the range 14–46 eV with 99% confidence level.

At the University of Guelph in Ontario, Canada, John J. Simpson has recently measured the tritium endpoint spectrum using tritium implanted in silicon crystals. He obtained a ν_e mass limit of 70 eV, comparable to that obtained by K.-E. Bergkvist a decade ago. However, Simpson believes that in a future experiment he could set a 20-eV limit and measure a mass of 35 eV with a 95% confidence level.

Another experiment at the Savannah River reactor is being prepared by a Georgia Tech–University of South Carolina group led by Tino Ahrens and T. P. Lang (Georgia Tech). They will use coaxial scintillators whose outer detector contains lithium to detect the neutron produced. The inner detector can be either a deuterated or undeuterated scintillator, and the proton or positron produced can be detected. Thus they can observe for the deuteron both the neutral- and charged-current reactions and for the proton the charged-current reaction. At present, their equipment is at 15.4 meters but it can be moved as close as 13. The group plans to start taking data this fall.

At Brookhaven Larry Sulak and his collaborators at Harvard and the University of Michigan have been looking for oscillations at the AGS, where the 30-GeV accelerator was operated at 1.5 GeV to produce a pure ν_μ beam at 150–250 MeV. Unlike the other experiments discussed, they look for loss of ν_μ and the appearance of ν_e. Sulak told us that the Brookhaven experiment is sensitive to smaller masses than indicated by the reactor experiments. At this writing, the group is still analyzing 400 tapes of data from their run, which ended last November.

Impact of oscillations. Neutrino oscillations are of course an intriguing idea. After summarizing the present evidence at the APS meeting, Sheldon Glashow (Harvard University) remarked "Neutrino masses and mixing are suggested but not demanded by grand unification theories." Neutrinos changing their type on the way from the Sun to Earth would be one way out of the solar-neutrino puzzle. Massive neutrinos would also be of great importance cosmologically. Because there are roughly a billion relic neutrinos for each nucleon in the Universe, neutrinos with masses in excess of a few eV would dominate the total mass in the Universe. —GBL

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CERN hopes to finish LEP by 1986

If you thought a herd of bison grazing in the middle of the Fermilab accelerator was impressive, consider a colliding-beam accelerator whose electrons and positrons will circle more than a dozen villages in two countries. That is in fact the scale on which the Europeans hope to be doing high-energy physics by 1986.

At the June meeting of the CERN Council, the CERN management submitted its formal proposal for the construction of the LEP (Large Electron–Positron) colliding-beam accelerator. The acronym is understated. The LEP design calls for an underground ring 30.6 kilometers in circumference, straddling the French–Swiss border near Geneva. Where the accelerator passes under the Jura mountains west of CERN, three of the collision points and their experimental halls will be as much as a half mile below ground level.

These gargantuan dimensions are necessary if synchrotron radiation losses are to be kept within acceptable bounds as the electrons and positrons circulate at energies up to 130 GeV. The smaller the radius of curvature, the greater the radiation. Proton accelerators of far more modest dimensions achieve energies up to 500 GeV, because the heavier protons radiate much less as they circulate. But even with a 30-km circumference, LEP will have to draw 250 megawatts of electrical power from the French electricity grid when operating at 90 GeV, primarily to make up these radiation losses.

Herwig Schopper, who will become director-general of CERN next January, recently told the CERN Committee of Council that LEP could be operational at its initial physics stage (the "one-sixth stage") by 1986, significantly earlier than previously projected. The "one-sixth" refers to the operation of LEP at 16 megawatts of rf power, 1/6 of the full rf input when all of the copper rf cavities are operational. With its full complement of copper cavities, LEP is designed to achieve energies up to 90 GeV in each of the colliding beams. The ultimate goal of 130 GeV per beam will require superconducting rf cavities; this is not expected until some time in the next decade.

Even at the one-sixth stage, with 50-GeV circulating beams, electrons and positrons would collide at center-of-mass energies of 100 GeV—more than enough, it is fervently hoped, to produce the Z^0, the much-sought-after neutral quantum of the weak force. The Weinberg–Salam theory that proposes to unify the weak and electromagnetic forces, predicts a mass of about 90 GeV for the Z^0. Its charged cousins, the W^+ and W^-, are expected to be somewhat lighter, but because they would be produced only in pairs in e^+e^- collisions (requiring an energy equal to twice the W mass), their discovery must await the installation of all 768 copper rf cavity assemblies.

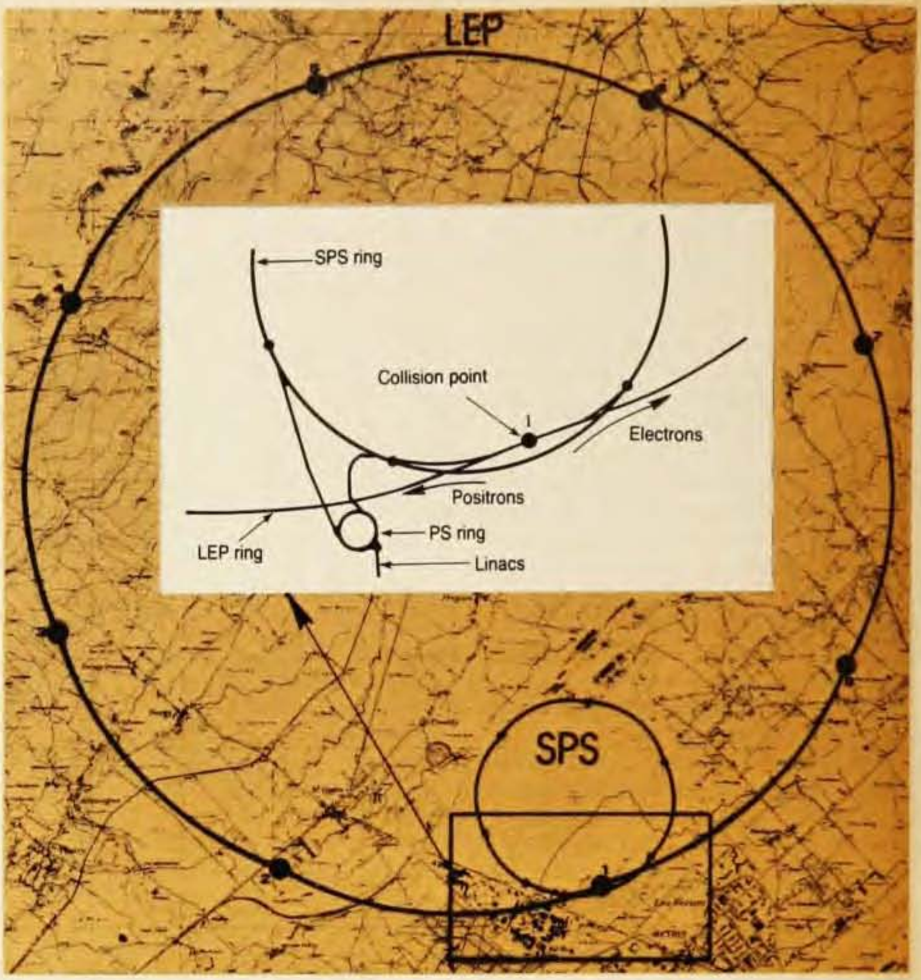
Now that the construction of LEP has been formally proposed, and strongly recommended by the CERN Scientific Policy Committee, the issue will be debated at home in each of the European Organization's twelve member states. With a final decision expected next June, construction could begin early in 1982. LEP is expected to cost more than half a billion dollars. But by phasing out the ISR proton storage rings and curtailing the operation of the 600-MeV synchrocyclotron, CERN expects to finance the construction of LEP out of its ordinary operating budget.

The injection system for LEP will make use of the existing Proton Synchrotron and Super Proton Synchrotron. It begins with a 200-MeV electron linac, followed by a positron-production target and a positron linac. The electrons and positrons are to be accumulated in a 600-MeV storage ring, after which they are accelerated to 22 GeV in the PS and SPS, which finally injects them into LEP. There the electrons and positrons circulate in opposite directions through the same 30-km vacuum pipe, in bunches a few centimeters long. The bunches are squeezed down to fractions of a millimeter in height and width, and made to intersect at eight collision points around the ring, where space will be provided for experimental setups. The design luminosity (collision rate per unit scattering cross section) at 90 GeV per beam is 10^{32} cm^{-2} sec^{-1}, comparable to those of PETRA (Hamburg) and PEP (Stanford), the largest existing e^+e^- collider rings. To sustain this luminosity, the LEP ring would have to be refilled with electrons and positrons every two hours.

With a luminosity of 3×10^{31} cm^{-2} sec^{-1} when the beams are tuned to the resonant energy corresponding to the Z^0 mass, one would expect to produce Z^0's at a rate of about 10^8 per year. Surely one doesn't need that many Z^0's to prove their existence. But the decay modes of this mediator of the weak interaction should offer crucial insight into the weak interaction and its relationship to the other fundamental forces.

In particular, because the Z^0 can decay into pairs of neutrinos, the more different kinds of neutrinos there are, the greater is the sum of the probabilities for such decays. Thus the mean lifetime of the Z^0 would be a direct measure of the number of different lepton pairs in Nature. We already know of three: the electron, the muon and the recently discovered tau, each with its own neutrino. (See page 17.)

Closely related to the different lepton types are the "flavors" of the strongly interacting quarks. The SU (5) scheme of Sheldon Glashow and Howard Georgi (Harvard), which seeks to unify the electro–weak and strong interactions, assigns a pair of quark flavors to each fundamental lepton—for example, strangeness and charm are presumed to go with the muon and its neutrino. Corresponding to the three known lepton pairs, five quark flavors have already been found, and a sixth ("truth") has been anxiously sought at PETRA, thus far to no avail.



The LEP colliding-beam accelerator, with a circumference of 30.6 km, will straddle the French–Swiss border near Geneva. Electrons and positrons injected in opposite directions will be accelerated to 90 GeV (eventually 130 GeV), and made to collide at eight intersection points around the ring. The injection system (insert) will include the Proton Synchrotron and Super Proton Synchrotron currently in operation at CERN. LEP may be ready to do physics by 1986.

Thus LEP promises to probe the inventory of fundamental objects in two ways at once: The lifetime of the Z^0 will tell us how many lepton–quark "generations" to expect, and the expanded energy range for e^+e^- collisions will permit us to seek them out directly, eventually up to a center-of-mass of 260 GeV. And beyond these anticipated riches, one must be prepared to find the totally unexpected in this *terra incognita*.

The LEP design prescribes 22 kilometers of bending magnets for the circulating beams. Because the radius of curvature is so large, the required bending fields are quite modest by high-energy standards—little more than a kilogauss at 130 GeV. Such low field intensities will permit a particularly inexpensive new design to be adopted for the bending magnets. Instead of being built of closely packed steel laminations, the magnet cores will consist of steel laminations sandwiched between layers of mortar. Prototype tests at CERN have found that these magnets exhibit satisfactory mechanical and magnetic properties at half the usual cost.

By constructing LEP alongside the 400-GeV SPS, CERN leaves open the possibility that the two accelerators may one day be linked to form a proton–electron collider. Just such a machine (but with more modest electron energies) is under active consideration for construction at Hamburg's DESY laboratory. The proposed HERA machine, which would collide 820-GeV protons with 30-GeV electrons, has been a source of some concern for the advocates of LEP. If the Germans were to decide to use superconducting rf cavities, the first (e^+e^-) phase of HERA might well reach energies sufficient to produce the Z^0 before LEP does, stealing much of its thunder. But Schopper, the present director of DESY, has given assurance that the first phase of HERA will not reach the Z^0 energy. (See PHYSICS TODAY, June, page 84.)

With the beams injected into LEP at 22 GeV, the lower end of LEP's energy range will begin just above the maximum energies available to PETRA and PEP (19 GeV per beam). Because of the enormous synchrotron radiation losses at the higher energies, major efforts are under way to make the rf system as efficient as possible. In collaboration with European industry, CERN is seeking to improve the efficiency of the klystrons or tetrodes that would feed the rf energy. Efforts at Stanford and Los Alamos to develop newer rf devices—the so-called trirotron and gyrocon—are being closely watched. CERN is also investigating a novel idea for reducing heat losses in the 353-megahertz rf cavities by transferring the rf energy into low-loss storage cavities during the time interval between the passage of particle bunches. And for the longer-range future, various European groups are working together on superconducting cavities for the final stage of LEP.

In a direct attempt to eliminate most of the synchrotron-radiation loss in high-energy e^+e^- colliders, Burton Richter and his colleagues at SLAC have designed a first-generation single-pass linear e^+e^- collider (PHYSICS TODAY, January 1980, page 19). By exploiting the two-mile linear accelerator already existing at SLAC, they hope to be producing Z^0's before LEP—admittedly at a somewhat lower luminosity.

The proton–antiproton collider rings scheduled for completion at CERN and Fermilab in the next two years will also have enough energy to produce the Z^0 and the W's. But these hadronic beams, involving the collision of three quarks with three antiquarks, are much messier than the coming together of the pointlike electron and positron. The weak intermediate bosons Z^0 and $W^{\pm}$ will very likely be produced in profusion in these $p\bar{p}$ machines, but they will have to be extricated from a copious hadronic background. —BMS

Refrigerator cools to 50 microkelvin

A double-stage nuclear demagnetization refrigerator promises to allow experiments at temperatures an order of magnitude lower than previously available. The new cooling device can not only reach record low electronic temperatures of 50 microkelvins but can maintain these temperatures long enough in an apparatus large enough to cool samples within it. The apparatus was developed at the Kernforschungsanlage Jülich in West Germany. Experimenters there have cooled about 2 kg of copper to an electronic temperature of 48 microkelvins and kept it below 60 microkelvins for more than two days. At the same time, in Japan, a group from the Institute for Solid State Physics at the University of Tokyo has reported equally low temperatures with a similar method but in a much smaller device.

The Jülich group consists of Robert M. Mueller, Christoph Buchal, Rudolf Folle, Minoru Kubota and Frank Pobell.[1] Members of the Tokyo team are K. Ono, S. Kobayasi, M. Shinohara, K. Asahi, H. Ishimoto, N. Nishida, M. Imaizumi, A. Nakaizumi, J. Ray, Y. Iseki, S. Takayanagi, K. Terui and T. Sugawara.[2]

The refrigerators developed in Jülich and Tokyo do not involve any new cooling technique but rather very meticulous engineering of existing techniques, which have themselves evolved to more efficient states. A major feature in the design of the refrigerator developed at Jülich was to reduce the heat leaks—by maximizing mechanical stability and by minimizing the use of organic material—and to enhance the cooling power and the thermal conductivity of the system. Both experiments used a commercial He^3–He^4 dilution refrigerator to precool the first stage to temperatures of between 15 and 25 millikelvins. The next two stages employed the adiabatic nuclear demagnetization technique pioneered by Nicholas Kurti of Oxford University in 1957. Copper is often chosen as the medium in demagnetization because of its high thermal conductivity. Indeed, Olli Lounasmaa and his coworkers at the Helsinki University of Technology in Finland (PHYSICS TODAY, December 1979, page 32) last year used[3] a double-stage copper demagnetization technique to obtain the lowest temperature ever measured—50 nanokelvins. This temperature was that of the nuclear spin system; the temperature of the conduction electrons remained higher—about 0.4 mK. Electronic and nuclear spin temperatures are not necessarily the same at these low temperatures because the spin-lattice coupling is reduced.

Copper is not as suitable a choice in the first stage of the systems designed to obtain low electronic temperatures and high cooling powers. The reason is that the entropy of copper in a magnetic field of 8 tesla is removed most effectively below 5 mK, a temperature at which the cooling power of the helium dilution refrigerator drops sharply. (See figure.) Thus both the German and the Japanese groups opted to use, in their first stage, so-called "hyperfine enhanced materials." These materials are intermetallic compounds containing rare-earth ions (specifically, in this application, praseodymium ions) in the singlet ground state. When an external magnetic field is applied to such praseodymium compounds, it induces a hyperfine field at the nucleus that is an order of magnitude more than the applied field. Thus one can use these compounds at a much lower magnetic field to get, for the same temperature, a much larger entropy reduction per unit volume. By contrast to copper, compounds such as $PrNi_5$ in a field of 8 T can experience a large drop in entropy around 15–25 mK, where the helium dilution refrigerator is still quite efficient. (See figure.)