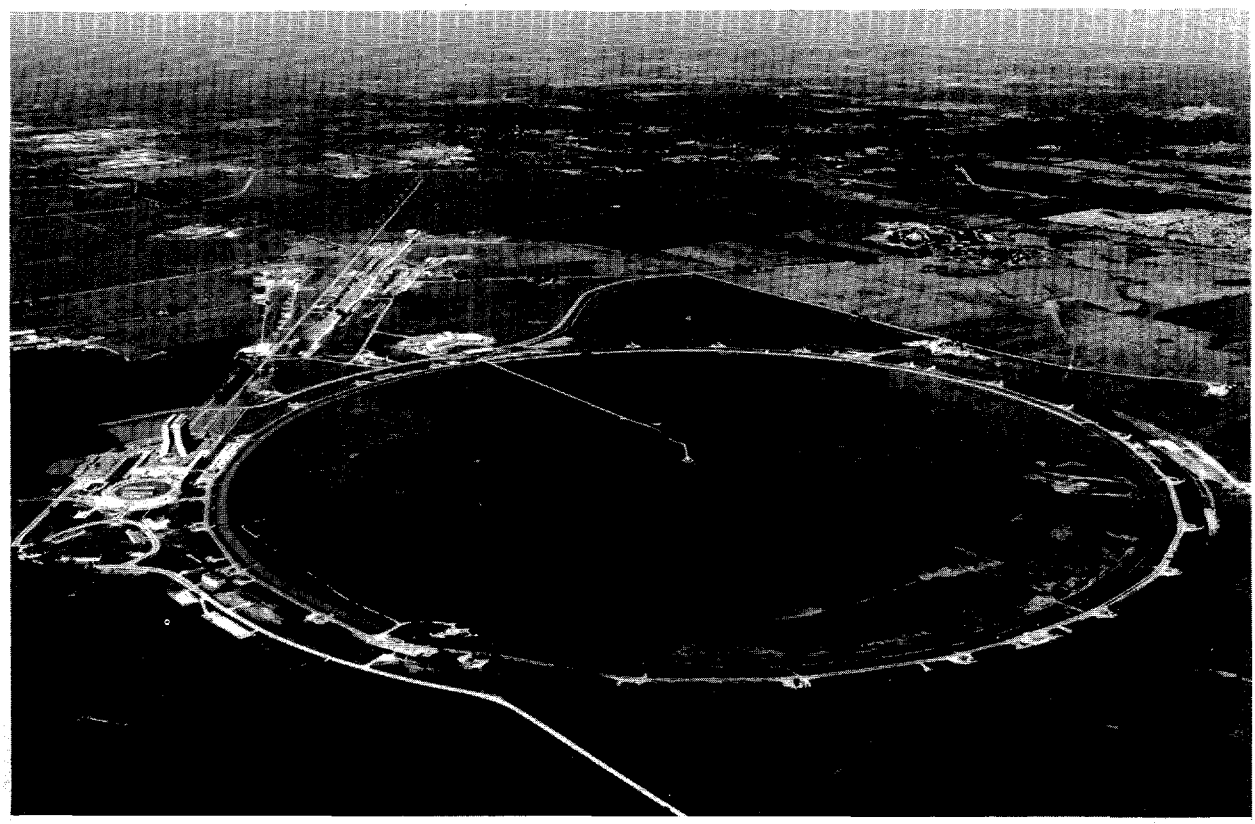

Figure 13. Aerial view of the Fermi National Accelerator Laboratory.

the Z. They made a beam of neutrinos by crashing high-energy protons into metal targets and filtering out all the other debris; then they directed this neutrino beam onto a massive detector to see whether any rebounded. But European physicists had already performed a similar experiment at CERN, using much lower-energy neutrinos, and found the first candidate for a neutral current event, in which a neutrino had apparently knocked a single electron out of its atom.

Other neutral current events, in which a neutrino collided with an atomic nucleus and rebounded sharply, also began to turn up in increasing numbers at both Fermilab and CERN. The Europeans had been working with their detector for several years, however, and knew its behavior better than the American group understood their newer equipment. CERN was the first to announce conclusive evidence for neutral currents, in the summer of 1973, and the Fermilab team soon confirmed the find. With this discovery of neutral currents, the case for a unified gauge theory of the weak and electromagnetic forces became much stronger.

The electroweak theory says that the charged leptons—the electron and muon—must be paired with their respective neutrinos. When an electron neutrino interacts with anything, either a W^+ or Z conveys the weak force. If a W^+ conveys the force, the neutrino converts into an electron. Similarly, a muon neutrino can only change into a muon. Both neutrinos retain their identities, however, if a Z is involved.

What's more, the electroweak theory permits only *left-handed* leptons—those whose spin vectors are aligned opposite their direction of motion—to participate in these exchanges. Right-handed *anti*leptons like the positron can take part, too, but right-handed leptons and left-handed antileptons cannot. No such restrictions apply when these particles feel the electromagnetic force carried by a photon. Thus the electroweak theory explains how the weak force violates parity, distinguishing between left and right, while the electromagnetic force does not.

When quarks were first proposed in 1964, a number of physicists figured they should be closely related to the leptons. Prominent among them were Glashow and Bjorken, who postulated another, fourth quark they called the *charmed* quark (c).