than the muon. With over a hundred such events in hand by the summer of 1976, Perl's group announced the discovery of the *tau* (τ) lepton at a mass of about 1.8 GeV. Detailed analyses also showed that a new and different neutrino, called the *tau neutrino* (ν_τ), was being produced when the tau decayed. Thus there was a *third* pair of leptons to be reckoned with.

Advocates of quark-lepton symmetry therefore postulated another pair of quarks, and experimenters at Fermilab were not long in finding the first one. Led by Leon Lederman (who later became Director of Fermilab), a group of physicists was ramming high-energy protons into stationary metal targets and searching for muon pairs among the debris. By the summer of 1977 they had accumulated sufficient evidence to announce the discovery of three *upsilon* particles with masses near 10 GeV. Like the J/psi, these particles were neutral and survived a long time by subatomic standards. Theorists immediately figured these upsilons were combinations of a *fifth* quark paired with its antiquark. Detailed measurements made in Germany later that year and in 1978 showed that the charge of this quark had to be -1/3, like that of the down and strange quarks. The new quark was dubbed *bottom* or *beauty* (*b*).

Particles known as B-mesons, containing a bottom quark plus an up or down quark, were first discovered in 1983 at the Cornell Energy Storage Ring. Physicists working at CESR have pioneered the studies of these particles, which may be the key to understanding CP violations.

Once the fifth quark had been discovered, the search began for the sixth, called *top* or *truth* (*t*). New accelerators and storage rings have been built during the past 10 years whose primary goal was to find this quark, but it has not turned up as yet (early-1990). Still, few physicists doubt it will eventually be found, once a powerful enough machine is built. So firm is the belief that quarks and leptons come in pairs, that they figure the top quark must simply be too massive to be produced at existing devices.

This is a telling measure of how seriously quarks are taken today—and a tribute to the performance of American high-energy physicists. Not only was the quark model, and much of the electroweak theory, developed by U.S. physicists, but crucial work in confirming these ideas was carried out at each of the three national laboratories—Brookhaven, Fermilab, and SLAC.

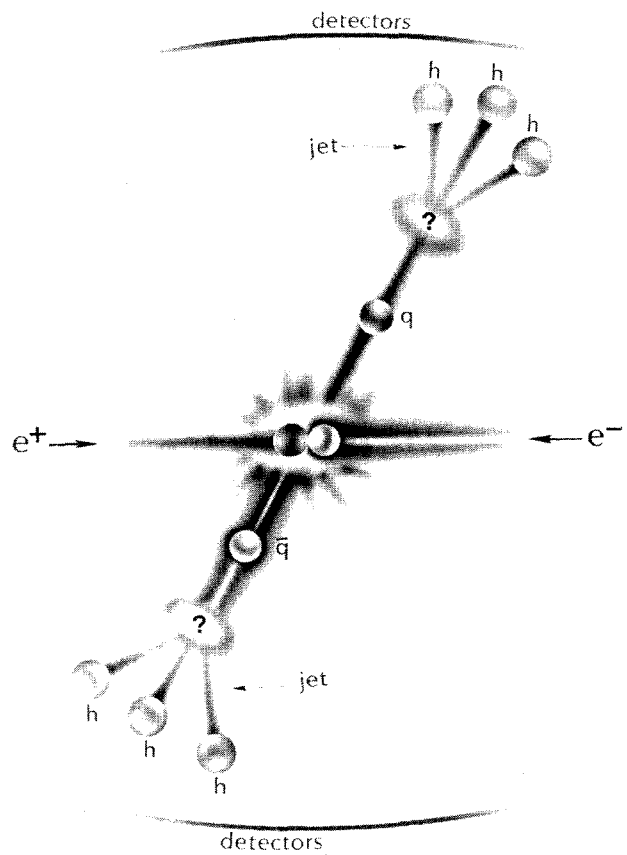

Figure 18. Back-to-back jets of hadrons arising from quark-antiquark product in an electron-positron collision.