have strangeness 0. Physicists say that the strong force "conserves strangeness" while the weak force need not conserve it.

For years physicists had expected that the laws governing subatomic forces had to be symmetric with respect to reflection in a mirror. Everyday objects might appear different in a mirror, which swaps left for right and vice-versa, but not subatomic processes. If a particle interaction occurred with a given strength, its mirror image ought to occur with equal strength, too, or so most physicists thought. Called the conservation of *parity,* this principle of left-right symmetry indeed holds true for the strong force.

In the summer of 1956 Tsung-Dao Lee and Chen Ning Yang began to examine whether parity conservation actually held true for the weak force, too. After careful study of the existing data, these two Chinese-American physicists concluded that there was no experimental evidence for such a belief; it was merely a strong theoretical expectation. To explain certain odd decays of kaons, Lee and Yang proposed that parity conservation might actually be *violated* by the weak force and suggested ways to test their hypothesis. Their bold proposal was tantamount to saying that the weak force could tell left from right.

This prediction was borne out later that year and in early 1957 by three experiments done by physicists from Columbia, the University of Chicago, and the National Bureau of Standards. Parity conservation is indeed violated in beta decay and in pion decay. The decay particles are emitted in preferred directions that do *not* appear the same under mirror reflection. The proofs were so clear-cut that Lee and Yang won the 1957 Nobel prize in physics, the youngest scientists ever to receive it.

Further experiments at Brookhaven indicated that the weak force violated parity not just a little but *maximally*. Neutrinos emerging from weak decays always have their spin vectors aligned opposite their direction of motion, never along it. Physicists say neutrinos are "left-handed." On the other hand, antineutrinos are "right-handed;" the antiparticle of the neutrino always has its spin vector pointing along its trajectory.

Thus the violation of parity by the weak force was evidence of an asymmetry between the world of matter and that of antimatter. With the strong force alone, things had been fine: matter and antimatter behave the same way. But not when the weak force became involved. To rescue the situation, some theorists proposed that perhaps nature was symmetric under a *combined* operation. "If one performs a mirror reflection and converts all matter into antimatter," wrote Yang in 1959, "then all physical laws remain unchanged." This new symmetry, which became known as "CP invariance," was believed to hold true for all forces—strong, weak, and electromagnetic.

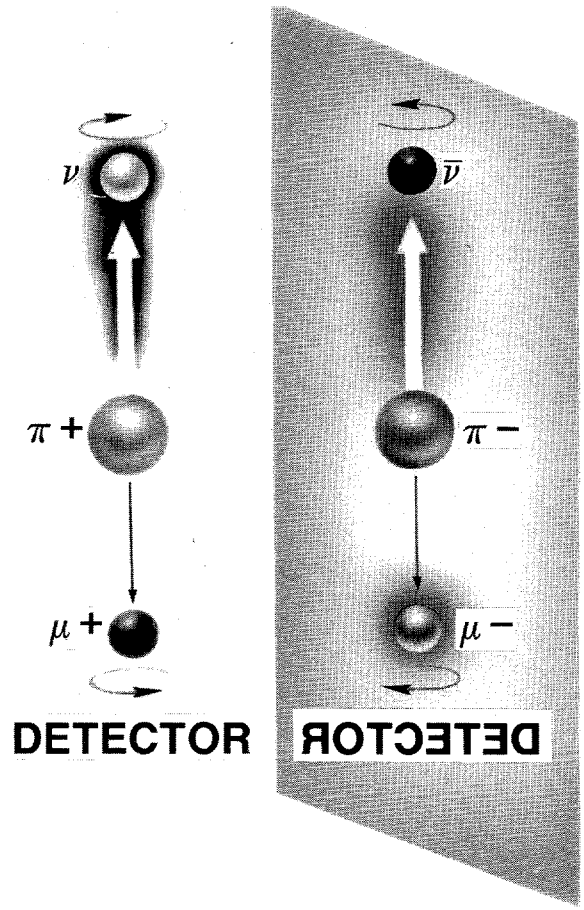

Figure 6. CP invariance in pion decay. If one replaces particles with antiparticles and performs a mirror reflection, the decay occurs at the same rate.

But here again the weak force failed to cooperate. If CP invariance held true, then a long-lived version of the neutral kaon could never decay into a pair of pions. In a 1964 experiment at the Brookhaven AGS, Princeton physicists led by James Cronin and Val Fitch proved that this decay indeed occurred, albeit less than one percent of the time. This small violation of CP invariance by the weak force meant that there remained a tiny asymmetry between matter and antimatter. For this discovery