of evidence that quarks carry an important new property.

One of the problems with the original quark hypothesis had to do with the difficulty of putting three quarks inside a baryon. According to Pauli's exclusion principle, two identical spin-1/2 particles cannot occupy the exact same turf. This is the main reason solid materials are so hard and impenetrable even though they are mostly empty space. But with certain baryons like the omega-minus, physicists needed to put *three* identical quarks into the same pot.

One way around this difficulty was to suppose that these quarks were not really identical, after all, rather they carried some additional property that was in fact *different* from one quark to the next. Not much was made of this idea until 1971, however, when Gell-Mann used it to explain why the neutral pion disintegrated nine times faster than first expected. If each type of quark—up, down, and strange—came in three distinct varieties, then the exclusion principle would not be violated by baryons, and the pion decay rate would increase by a factor of 3^2, or 9, as observed.

Gell-Mann dubbed the new, threefold property *color*. Quarks, he said, came in three different colors, arbitrarily chosen to be red, green, or blue. Thus the three strange quarks inside the omega-minus are in fact different: one red, one green, and one blue. The *combination* of these three colors—like the combination of red, green, and blue light on a television screen—results in zero net color. The mesons and baryons that leave deposits in particle detectors are completely colorless.

With the help of color, the quark model could readily explain the large numbers of hadrons being produced in electron-positron collisions. A quark and its antiquark could be created and subsequently metamorphose into hadrons that strike the detectors. Without color the quark model prediction still came in a factor of 3 below the observed rate of hadron production. With color, however, there are three times as many ways to make quark-antiquark pairs, and the rate increases accordingly.

A segment called the CEA Bypass, added to the Cambridge Electron Accelerator in the late 1960's, made it the first electron-positron storage ring to be built in the United States. By 1973 the CEA was able to extend the Italian measurements to higher energies. The rate of hadron production now proved to be greater than expected in the quark model, even if one assumed three kinds of

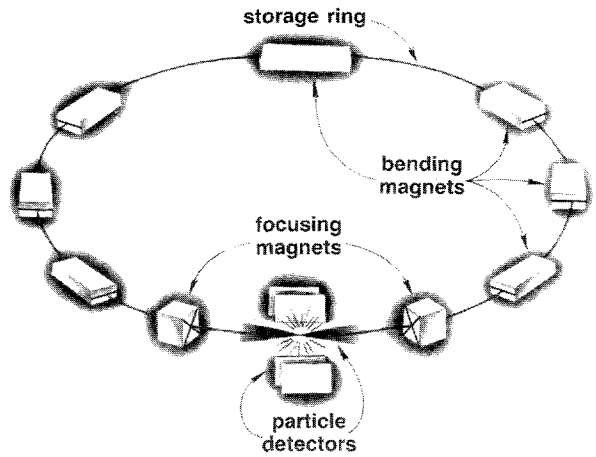

Figure 16. An electron-positron storage ring with detectors positioned near an interaction region.

quarks and three colors of each. Some physicists began to claim that this excess was evidence for a fourth quark, such as the charmed quark, but most preferred to wait for better data.

Just coming on line that year at SLAC was a new storage ring called SPEAR, an oval tube 200 yards in circumference that was fed electrons and positrons from the linear accelerator. Built under the leadership of SLAC physicist Burton Richter, a member of the original Stanford-Princeton group (and now Director of SLAC), it was designed to operate at total energies between 2 and 8 GeV and to generate a far greater number of collisions than previously possible.

In addition, Richter insisted that a new kind of particle detector be built at one of the two SPEAR interaction regions. The Mark I detector surrounded most of the collision point and had a strong magnetic field inside to help identify the particles produced and measure their properties. Earlier detectors at storage rings had been lacking on both counts, with consequent ambiguities in the interpretation of their results.

By the end of 1973 the first set of SPEAR measurements were complete, confirming the steady rise in the rate of hadron production at total energies above 3 GeV. As the rate was well beyond expectations based on three kinds of quarks with three colors, the case for a fourth quark became stronger.

In November 1974, while rechecking a few measurements at 3.1 GeV, SLAC and Berkeley physicists working on the Mark I detector discov-