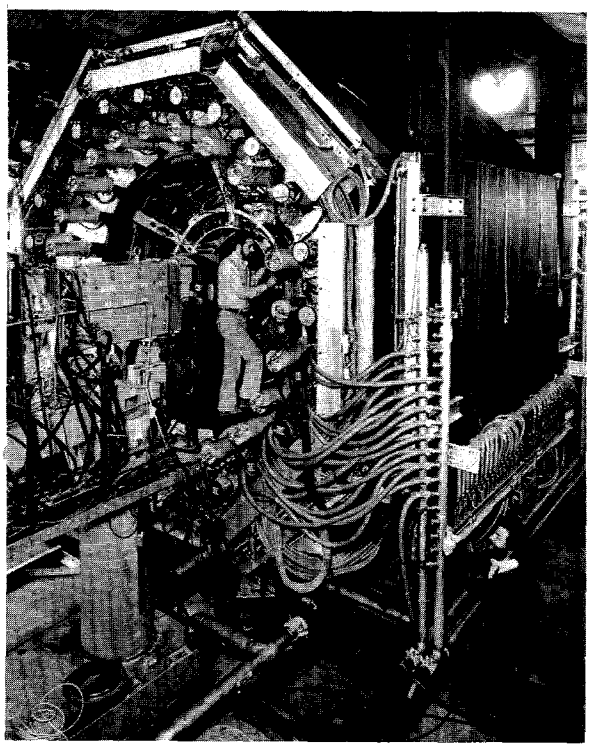

**Figure 17. The Mark I detector at the SPEAR storage ring.**

ered a tremendous increase in hadrons produced at that energy, which proved to be the signature of an astounding new particle. Electrons and positrons were feverishly annihilating one another to form an electrically neutral particle with a mass-energy of 3.1 GeV; it decayed into hadrons, a pair of muons, or another electron-positron pair. They named their discovery the *psi* ("ps-eye") particle.

Unknown to the SPEAR group, the exact same particle had turned up the previous month in a Brookhaven experiment led by Samuel Ting of MIT. Working on the AGS, his team examined what particles were produced when 29 GeV protons smashed into beryllium nuclei; they detected the new particle by careful study of its decay into electron-positron pairs. Ting called his discovery the *J* particle. The two discoveries were announced simultaneously at SLAC on November 11, 1974—a red-letter day in high-energy physics.

What was particularly striking about this particle was the fact that it survived about a thousand times longer than it should have, based on its large mass. Many physicists took this fact to suggest that the J/psi, as it has come to be known, carried some completely new property of matter never before encountered.

Advocates of the charmed quark were elated. They figured their hypothesis had been confirmed at last—especially after a second psi particle was discovered at SPEAR two weeks later with a mass of 3.7 GeV. These new objects, they argued, consisted of a charmed quark paired with its corresponding antiquark. To confirm this interpretation beyond a shadow of doubt, however, physicists needed to find a particle with "naked" charm, within which a charmed quark was *not* paired with its antiquark. Well before the J/psi discovery, Glashow and others had predicted such charmed mesons and baryons, containing a single, unpaired charmed quark, would turn up in high-energy experiments.

At accelerators around the globe experimenters raced to search for charmed particles. The first evidence for a charmed baryon was reported in early 1975 by a group of Brookhaven physicists working in neutrino scattering. Over a year later Berkeley and SLAC physicists found solid evidence for charmed mesons produced inside the Mark I detector. It was convincing proof that the charmed quark truly existed. In recognition of their key roles in the discovery of a whole new family of particles, Richter and Ting received the 1976 Nobel prize in physics.

Further evidence for quarks came in that year from SPEAR. Using a sophisticated computer analysis, SLAC physicists demonstrated that the hadrons emerging from electron-positron collisions were spewing out in back-to-back sprays, or *jets*. This pattern occurs naturally when a quark and its antiquark are produced in the ensuing fireball—and convert almost immediately into hadrons. Jets are the observable "footprints" left by quarks.

By the end of 1976, the physics community worldwide had come to believe in leptons and quarks as the fundamental basis of all matter. Although no quark had ever left a track in a particle detector, the evidence for them—which came largely from the MIT-SLAC and the SPEAR experiments—was undeniable. In addition to the four leptons, there were four known quarks: up, down, strange, and charmed.

During the excitement over the SPEAR discoveries, another group of SLAC physicists had been concentrating on a different kind of signal. Led by Martin Perl, they were searching for events in which an electron appeared in the Mark I detector together with a single muon, which would be evidence for the production of a lepton heavier