erful accelerators based on microwave-generating devices known as *klystrons,* which are now used to power radar installations throughout the world. At Stanford they are employed to deliver short bursts of extremely high-power electromagnetic radiation to a long copper tube through which electrons travel in compact bunches. These bunches ride along on the leading edge of the resulting electromagnetic wave that surges down the interior of the tube at close to the speed of light, imparting energy to the electrons all the way.

Funded by the U.S. Office of Naval Research, the early Stanford work culminated in the Mark III, a linear accelerator that eventually stretched over 300 feet and delivered electrons at energies above 1 GeV. Robert Hofstadter used this machine extensively during the 1950's to discern the structure of atomic nuclei and the nucleons by interpreting the patterns of high-energy electrons as they bounced off these targets. He proved that the proton and neutron are spheres of matter about a tenth of a trillionth of a centimeter across—about a hundred thousand times smaller than an atom. Hofstadter won the 1961 Nobel prize for this important work.

Related *electron scattering* experiments continued at circular accelerators completed during the early 1960's in Cambridge, Massachusetts, at Cornell and near Hamburg, West Germany. These machines pushed electrons to energies as high as 6 GeV. Using these electrons as probes, physicists studied the structure of the nucleons in finer detail, finding no evidence for any "lumpiness" in the distributions of their matter. They still looked like homogeneous mixtures of mass and energy.

When the Stanford Linear Accelerator Center (SLAC) finally began its experimental program in 1966, most high-energy physicists expected its users to continue these nucleon structure measurements to even smaller distances. With electron energies of 20 GeV, the accelerator could be used to probe features about a *quadrillionth* of a centimeter across. But few physicists expected any big surprises. Indeed, results from the the first electron-proton scattering experiment, presented in 1967, proved to be just a smooth continuation of the earlier findings. No lumps.

But in the fall of 1967 a group of physicists from the Massachusetts Institute of Technology (MIT) and SLAC itself began a series of experiments that would give quarks more credence. Led by Jerome Friedman and Henry Kendall of MIT

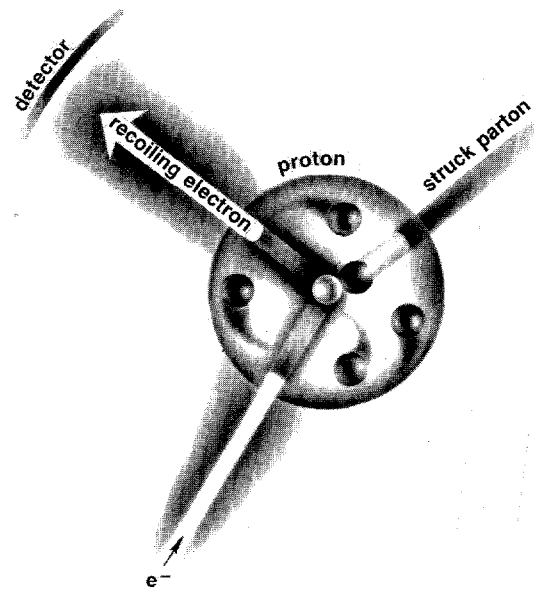

Figure 12. Parton picture of inelastic electron scattering.

and Richard Taylor of SLAC, this team began to study *inelastic* scattering, whereby the electron produced other particles as it ricocheted from the proton. Most of the earlier work had concentrated on so-called elastic scattering, in which no other particles are produced when the electron bashes into the proton.

Using two large devices called magnetic spectrometers, the MIT-SLAC team soon began to detect far more electrons bouncing off the proton at larger angles than expected—ten to a hundred times as many. One ready interpretation was that the inelastically scattered electrons had encountered tiny lumpms of matter deep inside the proton. It was an experience quite similar to what had occurred half a century earlier to Rutherford and his assistants, when they used beams of alpha particles to discover the atomic nucleus. Then too, physicists had encountered far too many projectiles scattering at large angles and concluded there must be something tiny responsible.

These ideas were assembled into a coherent theoretical framework by theorists James Bjorken of SLAC and Richard Feynman of the California Institute of Technology. Since a year before the MIT-SLAC experiment, Bjorken had been elaborating some of the quark ideas and had actually predicted there might be a large excess of electron scattering in the "deep inelastic" realm. Feynman happened along after the experiment, in mid-1968,