7. PHYSICS IN COLLISION

In the early 1970's another innovation in accelerator technology led to a jump in available energy that helped U.S. physicists discover the fourth quark. Until that time almost all important high-energy physics research had employed what are known as *fixed-target* facilities. Physicists smashed energetic subatomic particles into stationary targets and examined the debris thrown forward into detectors. Although this approach has certain advantages, such as being able to place huge volumes of material in the path of weakly interacting particles like neutrinos, it also has a number of key drawbacks.

At energies where relativity becomes important, most of the probing particle's energy is used to fling collision fragments away, somewhat like clobbering a Volkswagen with a trailer truck. The fraction of the energy available for making new, exotic, and *heavy* particles— such as the massive W and Z bosons—becomes smaller and smaller as the energy grows. Even though Fermilab's synchrotron could accelerate protons to 300 GeV by 1973, for example, less than 8 percent of this figure, or 24 GeV, was available to make new particles. The rest was simply wasted on the debris.

By the late 1950's a few physicists had recognized this inherent limitation of fixed-target machines and begun to seek alternatives. If one instead took *two* beams of particles of equal energy and passed each beam through the other, they figured, almost all of the combined energy of any two colliding particles would be available to make new things happen. It would be somewhat like two trailer trucks colliding head-on.

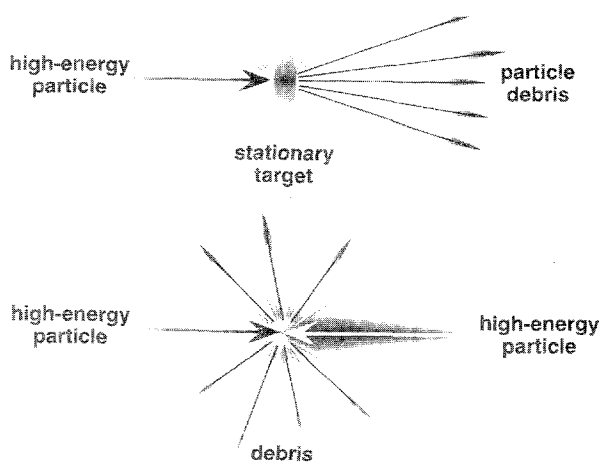

Figure 15. Fixed-target and colliding-beam experiments.

Given the incredibly small sizes of subatomic particles, however, the chances of a head-on collision occurring in a single crossing are miniscule. There is so much empty space between the individual particles in each bunch that they merely zoom past one another without interacting. But by putting the particles into circular devices called storage *rings* and circulating them in intersecting beams for hours at a stretch, physicists could improve their chances. With millions of beam-beam encounters per minute, smash-ups occur often enough to do experiments.

Only stable, charged particles such as the electron and proton can be stored in these rings. The first storage ring was built in 1958 by a small collaboration of Princeton and Stanford physicists. Shaped like the figure 8, it stored 500 MeV electrons in two separate rings and brought them into collision at a single cross-over point.

In the early 1960's Italian physicists demonstrated how to store both electron and positron beams in the *same* ring. One circulates clockwise at almost the speed of light, the other counterclockwise. Head-on collisions occur at a few fixed *interaction regions* around the ring, where physicists set up their detectors to examine the debris. Occasionally an electron and a positron annihilate each other, creating a momentary fireball of pure energy that quickly materializes as leptons or hadrons.

The first results from the Italian storage ring ADONE, which came in during the early 1970's, showed far greater production of hadrons in these electron-positron annihilations than most physicists had imagined. It was welcome news to the small but growing company who believed in quarks. The excess production of hadrons was a key piece