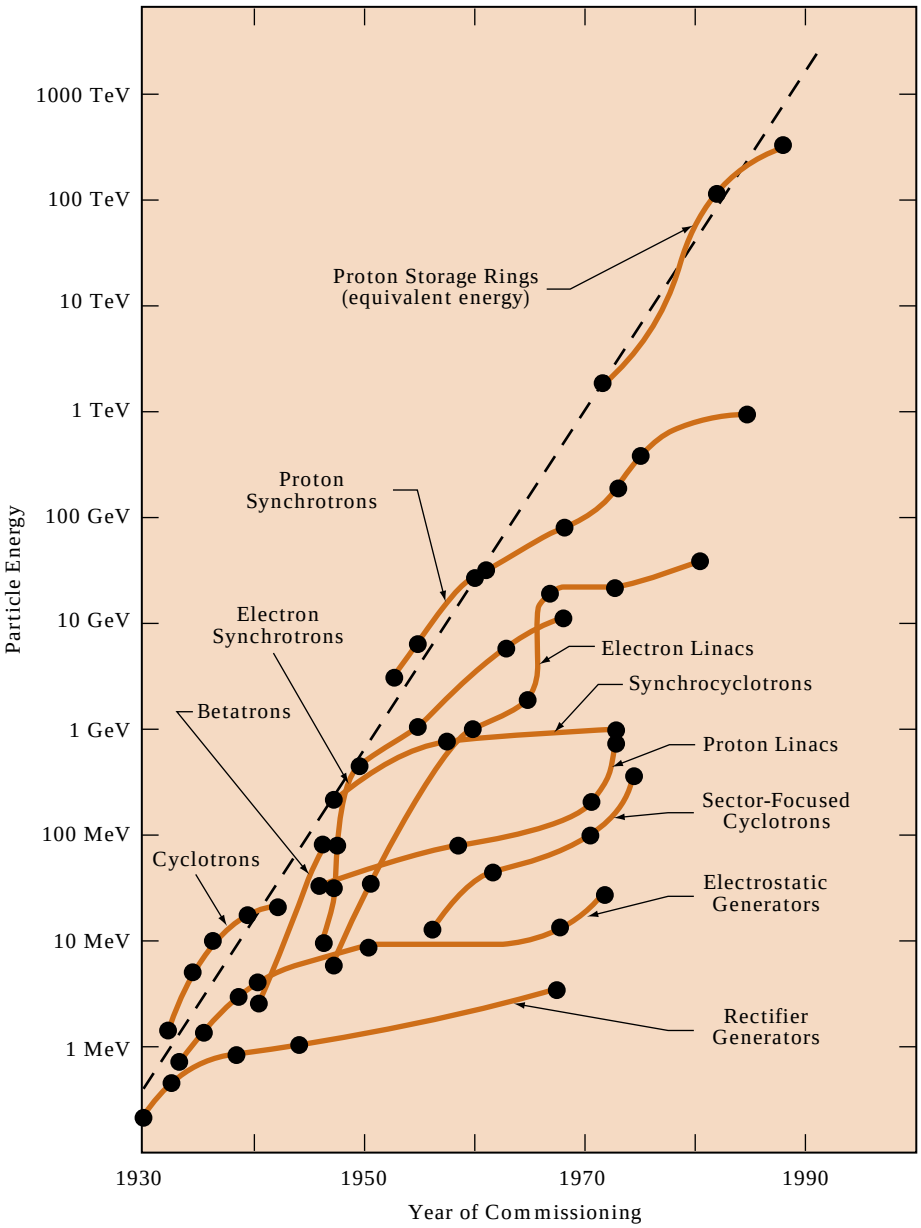
This relationship can be expressed quantitatively. To examine matter at the scale of an atom (about 10^{-8} centimeter), the energies required are in the range of a thousand electron volts. (An electron volt is the energy unit customarily used by particle physicists; it is the energy a particle acquires when it is accelerated across a potential difference of one volt.) At the scale of the nucleus, energies in the million electron volt—or MeV—range are needed. To examine the fine structure of the basic constituents of matter requires energies generally exceeding a billion electron volts, or 1 GeV.

A "Livingston plot" showing accelerator energy versus time, updated to include machines that came on line during the 1980s. The filled circles indicate new or upgraded accelerators of each type.



But there is another reason for using high energy. Most of the objects of interest to the elementary particle physicist today do not exist as free particles in Nature; they have to be created artificially in the laboratory. The famous $E = mc^2$ relationship governs the collision energy E required to produce a particle of mass m. Many of the most interesting particles are so heavy that collision energies of many GeV are needed to create them. In fact, the key to understanding the origins of many parameters, including the masses of the known particles, required to make today's theories consistent is believed to reside in the attainment of collision energies in the trillion electron volt, or TeV, range.

Our progress in attaining ever higher collision energy has indeed been impressive. The graph on the left, originally produced by M. Stanley Livingston in 1954, shows how the laboratory energy of the particle beams produced by accelerators has increased. This plot has been updated by adding modern developments. One of the first things to notice is that the energy of man-made accelerators has been growing exponentially in time. Starting from the 1930s, the energy has increased—roughly speaking—by about a factor of 10 every six to eight years. A second conclusion is that this spectacular achievement has resulted