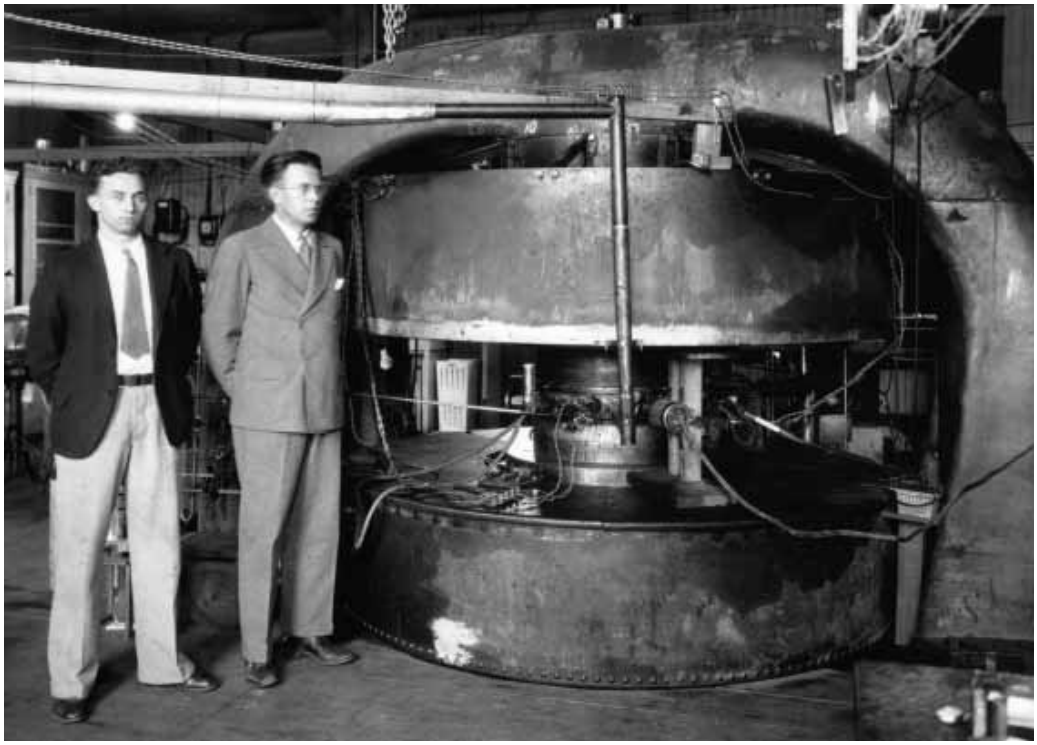

M. Stanley Livingston and Ernest O. Lawrence, with their 27-inch cyclotron at Berkeley Radiation Laboratory. (Courtesy Lawrence Berkeley National Laboratory)

from a succession of technologies rather than from construction of bigger and better machines of a given type. When any one technology ran out of steam, a successor technology usually took over.

In another respect, however, the Livingston plot is misleading. It suggests that energy is the primary, if not the only, parameter that defines the discovery potential of an accelerator or collider. Energy is indeed required if physicists wish to cross a new threshold of discovery, provided that this threshold is defined by the energy needed to induce a new phenomenon. But there are several other parameters that are important for an accelerator to achieve—for example, the intensity of the beam, or the number of particles accelerated per second.

When the beam strikes a target, its particles collide with those in the target. The likelihood of producing a reaction is described by a number called the cross section, which is the effective area a target particle presents to an incident particle for that reaction to occur. The overall interaction rate is then the product of the beam intensity, the density of target particles, the cross section of the reaction under investigation, and the length of target material the incident particle penetrates. This rate, and therefore the beam intensity, is extremely important if physicists are to collect data that have sufficient statistical accuracy to draw meaningful conclusions.

Another important parameter is what we call the duty cycle—the percentage of time the beam is actually on. Unlike Thomson's device, most modern accelerators do not provide a steady flow of particles, generally because that would require too much electric power; instead, the beam is pulsed on and off. When physicists try to identify what reaction has taken place, one piece of evidence is whether the different particles emerge from a collision at the same time. Thus electronic circuits register the instant when a particle traverses a detector. But if the accelerator's duty cycle is small, then all the particles will burst forth during a short time interval. Therefore a relatively large number of accidental coincidences in time will occur, caused by particles emerging from different individual reactions, instead of from real coincidences due to particles emerging from a single event. If time coincidence is an important signature, a short duty cycle is a disadvantage.

Then there is the problem of backgrounds. In addition to the reaction under study, detectors will register two kinds of undesirable events. Some backgrounds arise from particles generated by processes other than the beam's interaction with the target or another beam—such as with residual gas, from "halo" particles traveling along the main beam, or even from cosmic rays. Other backgrounds stem from reactions that are already well understood and contain no new information. Accelerators differ in terms of the presence or absence of both kinds of backgrounds; their discovery potential differs accordingly. The amount and kinds of background are directly related to the ease of data analysis, the type of detector to be built, or whether the desired results can be extracted at all.

In general, as the energy increases, the number of possible reactions also increases. So does the burden on the discriminating power of detectors and on the data-analysis potential of computers that can isolate the "wheat" from the "chaff." With the growth in energy indicated by the Livingston plot, there had to be a parallel growth in the analyzing potential of the equipment required to identify events of interest—as well as a growth in the number of people involved in its construction and operation.

And finally there is the matter of economy. Even if a planned accelerator is technically capable of providing the needed energy, intensity, duty cycle, and low background, it still must be affordable and operable. The resources required—money, land, electric power—must be sufficiently moderate that the expected results will have