UCRL 8565

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

BERKELEY, CALIFORNIA

UCRL-8565

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

Address Given at the Meeting of
The National Academy of Sciences

THE BEVATRON

Edward J. Lofgren

November 8, 1958

Printed for the U. S. Atomic Energy Commission

Address Given at the Meeting of
THE NATIONAL ACADEMY OF SCIENCES
Berkeley, California
November 8, 1958

8565

THE BEVATRON

Edward J. Lofgren

Twenty-eight years ago, in the opening lines of a paper presented at a meeting of this academy, Prof. Lawrence said, "Very little is known about nuclear properties of atoms, because of the difficulty inherent in excitation of nuclear transitions in the laboratory. The study of the nucleus would be greatly facilitated by the development of a source of high-speed protons having kinetic energy of about 1 million volt-electrons."[1] He went on to explain the idea of the cyclotron and the imminent possibility of producing 1-million-electron-volt protons with apparatus 10 cm in radius and having a 15,000-gauss magnetic field. Today a great deal is known about the nuclear properties of atoms, and much of this information came from the cyclotrons and related types of accelerators which stem directly from this early work of Prof. Lawrence. The Bevatron is one of the largest of this group of accelerators, and my purpose is to tell you what it is and how it works. Without apparent limit it seems that there is more and more to learn about nuclear particles. The experimental program of the Bevatron is one of the most important in this field, and in the following talk Prof. Alvarez will tell about the research which gives it that unique position.

For reasons which are simple enough to explain but which would take too much time to go into, it was not possible to apply the cyclotron idea as originally conceived to accelerators of energy greater than several tens of millions of electron volts. The necessary modifications to the original concept

---

[1] Science, LXXII, No. 1867, pg. 376.

in the form of the principle of phase stability were made independently by Prof. McMillan and Prof. Veksler. These modifications have made it possible to build synchrocyclotrons of several hundred million electron volts (Mev) energy and proton synchrotrons, like the Bevatron, of six billion electron volts (Bev), and the more recently completed Russian proton synchrotron of 10 Bev. Further extensions of the same line of development are incorporated in accelerators being built at the Brookhaven National Laboratory and at the CERN Laboratory, whose energy will be in excess of 25 Bev.

In the Bevatron, as in all accelerators stemming from the cyclotron idea, the ions are held in a circular path by a magnetic field and they are given repeated increments of energy by an accelerating electrode, which is excited with radio-frequency in synchronism with the circulating particles. Unlike the original cyclotron, the Bevatron keeps the radius of the particle orbit in the magnetic field approximately constant, with the magnetic field varying during the accelerating cycle, and the frequency of the accelerating voltage is not constant but increases as the speed of the particles increases.

The chief components of the Bevatron are identified and related in Fig. 1. The magnet which guides the protons in their circular path is made of four sectors of 50-foot radius, each separated by 30 feet. The vacuum tank extends through the magnet quadrants and the space between them, providing a path in the form of a ring with four flat spots, approximately 400 feet in circumference for the circulating protons. To establish an orbit as great as this, the particles must have an appreciable initial energy. Ten-Mev protons are supplied by the injection system, which is in itself two smaller accelerators operating in series. The first element is a ½-Mev Cockcroft-

Walton accelerator. In the Cockcroft-Walton a dc potential from a voltage-multiplying rectifier is applied in a straightforward manner to protons drawn from a hydrogen discharge. It is interesting to note that this was the type of accelerator used in 1932 to achieve the first transmutation of atoms with particles from an artificial source. The protons from the Cockcroft-Walton are injected into the 10-Mev linear accelerator. This type of linear accelerator is essentially a copper vacuum tank in which an alternating axial electric field is established. Hollow cylindrical tubes are placed at appropriate spacing down the axis of the tank so that the injected protons are inside the field-free space within the tubes when the direction of the applied electric field is adverse, and the particles are between the tubes so that they feel the full force of the field when its direction is favorable. This type of accelerator was invented by Prof. Alvarez in 1945 and is based upon earlier work by Prof. Lawrence and Prof. Sloan on another type of linear accelerator and upon the war-time development of radar. The 10-Mev protons are then injected into the Bevatron proper through the inflector, which guides them into their orbit. At this instant in time the Bevatron magnetic field is 300 gauss, which is just sufficient to hold them in an orbit of 50-foot radius. Radio-frequency power is then applied to the accelerating electrode. Its frequency is 0.4 megacycle, just equal to the rotational frequency of the ions. At each passage through the accelerating electrode the energy of the particles is increased by 1500 electron volts; simultaneously and continuously the magnetic field is increased to maintain a constant orbit radius, and the frequency of the accelerating power is increased to match the greater rotational frequency.

The accelerating cycle lasts approximately 2 seconds, during which time the magnetic field increases to 13,500 gauss and the frequency to 9.4 Mc, and the protons will have made 4,000,000 revolutions and attained an energy of 6.2 Bev. The cycle is repeated with a new batch of protons every 6 seconds.

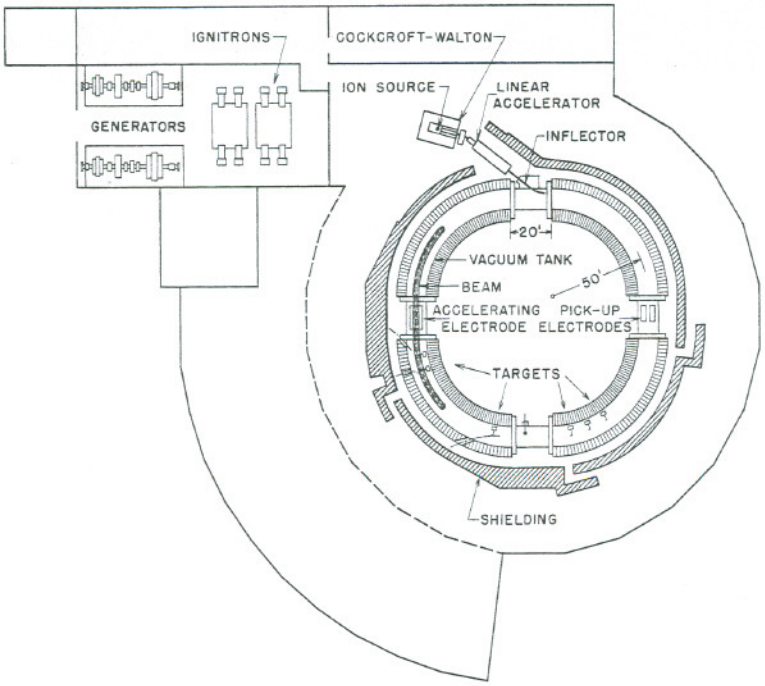
Figure 2 is a diagrammatic cross section of the Bevatron. When the 10-Mev protons are injected they fill most of the space between the magnet pole tips, approximately 1 foot by 4 feet, because of large radial and vertical oscillations. As the acceleration proceeds, these oscillations are damped, and the cross section of the beam is reduced to a few square inches, as indicated. The accelerated protons now form a tight bunch orbiting through the center of the tank. A target mechanism is then extended, lifting an appropriate target from its position on the bottom of the tank to the median plane and at a radial position just inside the beam bunch. The path of the beam is then perturbed, either by altering the radio-frequency or by energizing a small auxiliary magnet, and the beam is driven into the target. About 10^{11} protons are accelerated during each pulse, and the cycle is repeated ten times a minute.

In nearly all the experiments the interest is in the secondary particles, which are produced when the primary 6-Bev protons strike the nuclear matter in the target. All the familiar elementary particles are produced, as well as the more recently discovered K mesons, hyperons, and antinucleons. The secondary particles leave the target in a spray in all directions, with the more energetic ones oriented in a forward direction. This spray of particles

of various kinds and energies is difficult to work with directly. Sometimes the desired particle appears as only 1 in 10^4 to 10^6 undesired particles.

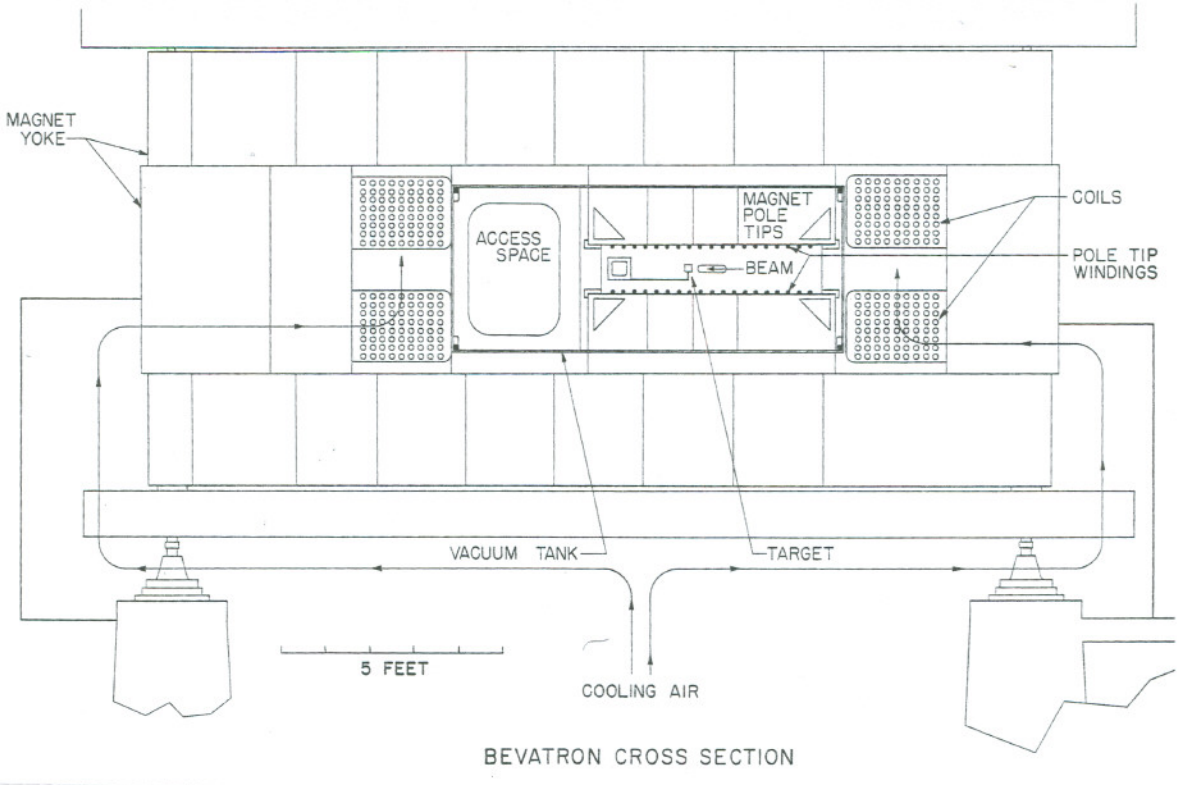
Important advances have recently been made in the means of analyzing, sorting, and focusing to provide relatively pure and homogeneous beams of the rare particles. Figure 3 is a diagram of one such system. The target in this case is in the Bevatron magnet, and an initial separation between the positively charged, neutral and negatively charged particles is made by the Bevatron field. The negatively charged particles are deflected 90° from the direction of the primary proton and pass through a hole in one of the Bevatron leg yokes. A further deflection occurs as the particles go through the magnet labeled M-1. These two deflections define a momentum, so that we now have negative particles of a given momentum but of several kinds -- pions, muons, K mesons and antiprotons. The beam is also diverging and requires a magnetic focusing lens, Q1, to render it parallel. The next step is to separate the various kinds of particles according to mass. To do this, the beam is passed through a velocity spectrumeter, where opposite transverse electric and magnetic forces are applied. Since the magnetic force depends upon velocity, these transverse forces can be balanced so that particles of any one chosen velocity are undeflected, and all other particles are deflected. Since the mixed particles have already been selected to have a constant momentum (mass X velocity), this deflection results in a separation according to mass. A final magnetic focusing lens, Q2, and collimators, C1 and C2, are placed just before the hydrogen bubble chamber used in this particular experiment. This particular arrangement of equipment has been used very effectively to separate both K^- mesons and antiprotons of momentum about 450 Mev/c for experiments with various bubble chambers and nuclear emulsions used as detectors.

The final illustration (Fig. 4) is a photograph of the Bevatron. The $\frac{1}{2}$ Mev Cockcroft-Walton is in the house at the right. The 10 Mev linear accelerator is in the center, and the Bevatron magnet curves off to the left.



BEVATRON

Fig. 1



BEVATRON CROSS SECTION

Fig. 2

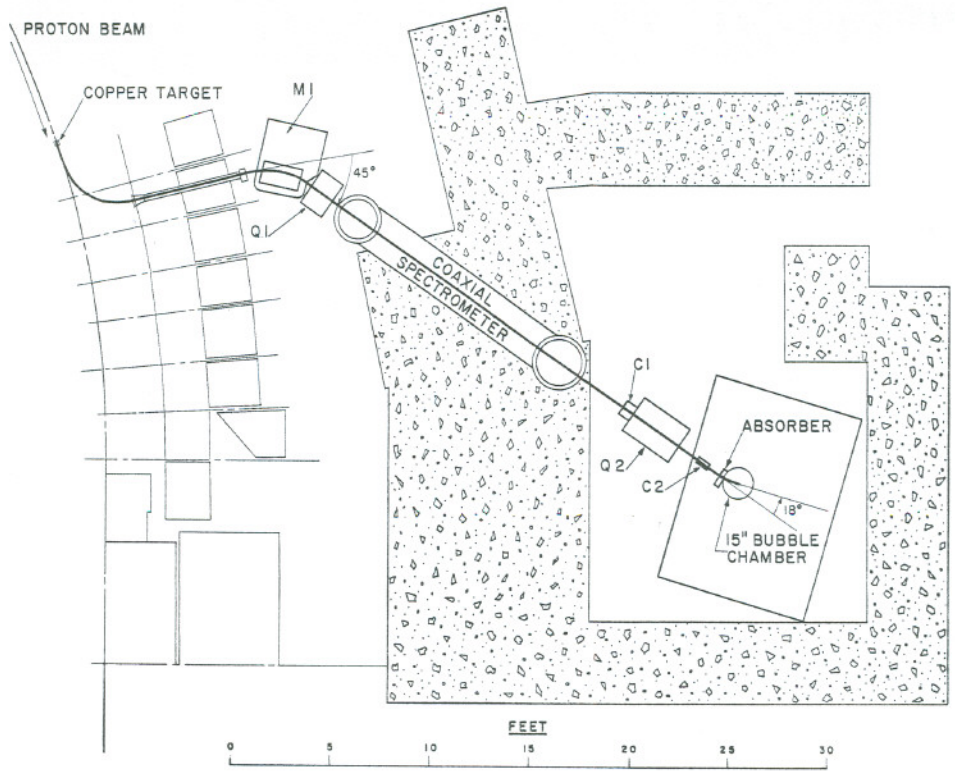

PROTON BEAM
COPPER TARGET
M1
45°
Q1
COAXIAL SPECTROMETER
C1
ABSORBER
Q2
C2
18°
15" BUBBLE CHAMBER
FEET
0
5
10
15
20
25
30

Fig. 3

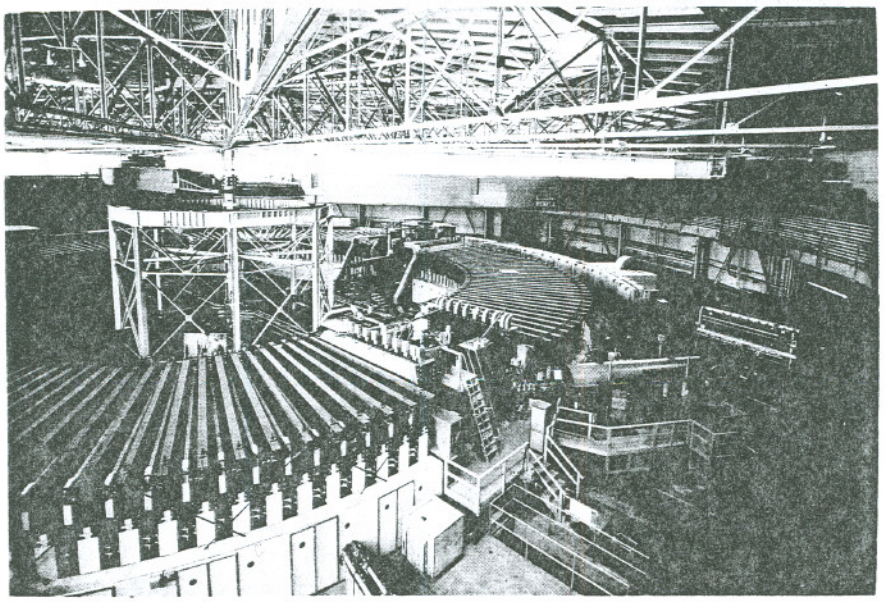


Fig. 4