Title
RADIATION LABORATORY.

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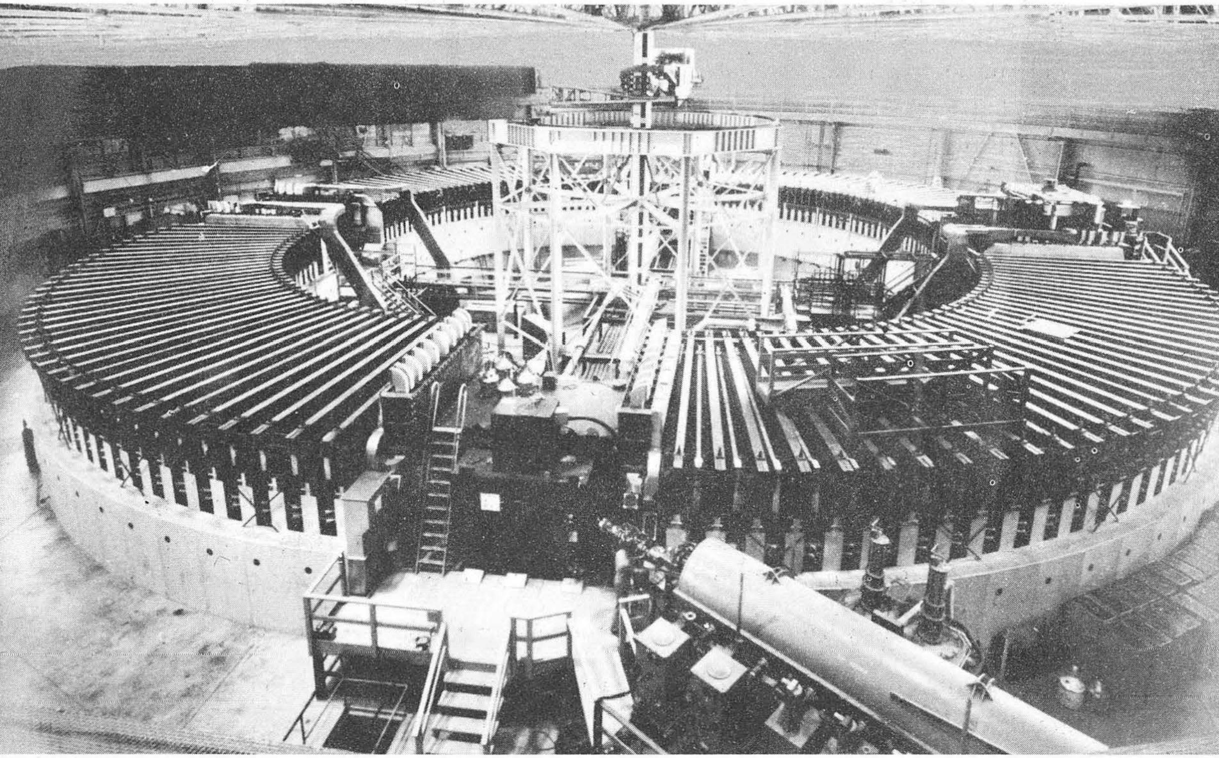
Radiation Laboratory

UNIVERSITY OF CALIFORNIA
BERKELEY



Welcome to the Radiation Laboratory. This pamphlet was prepared to give you an introduction to the Laboratory and its work. We hope you enjoy your visit with us.

THE LABORATORY

The Radiation Laboratory was established in 1936 as a part of the Department of Physics of the University of California. From the beginning much effort has been concentrated on the development of particle accelerators because of the great importance of these machines for probing the atomic nucleus.

The research program of the Laboratory has always had as its principal theme the investigation of the fundamental aspects of physical science. As the program and facilities expanded, interests spread beyond the field of physics into chemistry, biology, and medicine. The present research effort extends quite broadly over the entire range of basic research on the fundamental physical and chemical properties of matter and the application of radioactive substances to problems in biology, medicine, and related fields. The training of graduate students and junior scientists is tied into the research program and is regarded as an important phase of the Laboratory's work.

During the wartime period the Laboratory was engaged under the Manhattan Engineer District in the development of an electromagnetic isotope-separation process. This work led to the construction of a large plant at Oak Ridge for the electromagnetic separation of uranium isotopes. The Government sponsorship of research has continued on a large scale under the atomic energy Commission so that the Radiation Laboratory is now almost completely supported by the Commission through a contract with the University of California.

The Laboratory has a second site at the near-by town of Livermore.

The interest and cooperation of scientific workers everywhere have been gratifying and encouraging to members of this Laboratory.

Clark Kerr

Chancellor, University of California

DISCLAIMER

THE ATOMIC NUCLEUS

An atomic nucleus is made up of protons and neutrons held together by strong short-range forces. It occupies only a small fraction of the total volume of the atom and is substantially unaffected by electrical forces and by chemical or thermal effects by which the atoms themselves are combined into molecules or by which molecules may be split into atoms.

The English physicist Rutherford was the first man to succeed in altering the atomic nucleus; he discovered in 1919 that he could transmute nitrogen into oxygen by bombarding it with alpha particles from radium. This remarkable discovery opened the entire field of nuclear research and led to the discovery of artificial radioactivity and to the release of nuclear energy.

Physicists immediately began the search for artificial means to accelerate nuclear particles to higher energies than could be obtained from naturally radioactive sources. Greater quantity and variety of particles was also desired. The idea of the cyclotron was conceived by E. O. Lawrence in 1929 and has led in the years since to the development of ever larger and more powerful particle accelerators. The energy range of these machines has been extended to the point where particles produced by the bevatron, presently the most powerful accelerator in existence, are in the lower energy class of cosmic rays.

The probing of the atomic nucleus with particles of greater and greater energy is providing ever-increasing knowledge concerning the nature of its complex structure and of the tremendous forces that bind it together.

PARTICLE ACCELERATORS AT UCRL

From its establishment the Radiation Laboratory has given much attention to the development of particle accelerators in a constant effort to push nuclear research into higher and higher energy ranges. At the present time, the Laboratory has a group of accelerators in operation that allows a broad coverage in nuclear research. In Berkeley are the bevatron, the 184-inch synchrocyclotron, the 60-inch cyclotron, the 330-Mev electron synchrotron, and the 32-Mev linear accelerator with its associated 4-Mev Van de Graaff accelerator. Design work is well under way for a heavy-particle linear accelerator. In Livermore there is a Cockcroft-Walton accelerator in operation and a 90-inch cyclotron nearing completion.

These machines complement rather than duplicate one another and afford the experimenter a great latitude in the kind of research that may be undertaken.

The bevatron, the largest particle accelerator in existence, is described herein and some facts are given concerning its operation. Some information about the 184-inch and 60-inch cyclotrons, the synchrotron, and the linear accelerator is given on the back cover page.

THE BEVATRON

The bevatron was proposed in 1947 to take advantage of the newly discovered principle of phase stability in accelerators. It makes use of a varying magnetic field, provided by a ring-shaped electromagnet 135 feet in diameter. The field guides the protons in a circular path of constant size while they are being accelerated, whereas in the cyclotron the particles spiral out from the center and a magnetic field must be provided over the entire area enclosing the spiral.

Since the bevatron itself cannot start particles from rest, or even from low energy, they are first accelerated to an energy of 10 Mev in two auxiliary accelerators before being injected into the bevatron. First, the protons are generated in an ion source by means of an electrical arc discharge operated in hydrogen gas. The protons enter a Cockcroft-Walton accelerator where they are accelerated to an energy of ½ Mev, and then pass into a linear accelerator. The linear accelerator increases their energy to 10 Mev and injects them into the bevatron.

When the protons enter the bevatron a magnetic field of only 300 gauss is sufficient to guide them in their orbits. Each time they make a revolution, however, they get an accelerating push from an electrode inside the accelerating chamber. These increases of energy are synchronized with the rising magnetic field that must hold them to the correct orbits.

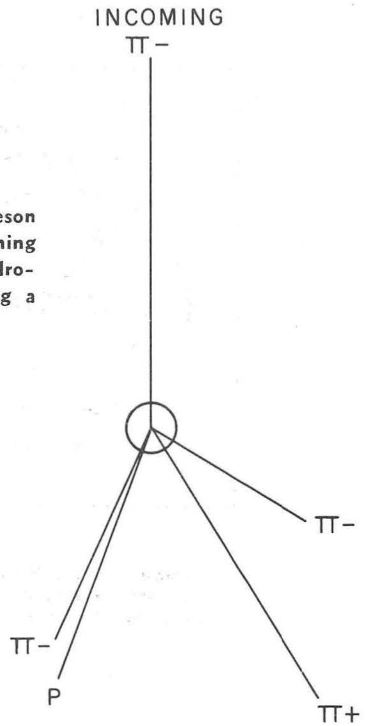
In a time of less than two seconds the protons have circled the accelerating chamber approximately 4,000,000 times and have reached an energy of 6.1 Bev. To hold them to their orbits, the magnetic field must increase to 15,500 gauss in this same period. By the end of the acceleration a pulse containing approximately 10^9 protons of maximum energy has been produced; then the cycle starts over. There are 5 pulses per minute.

On pages 6 and 7 are diagrams illustrating how the bevatron works and some data on its size and operation.

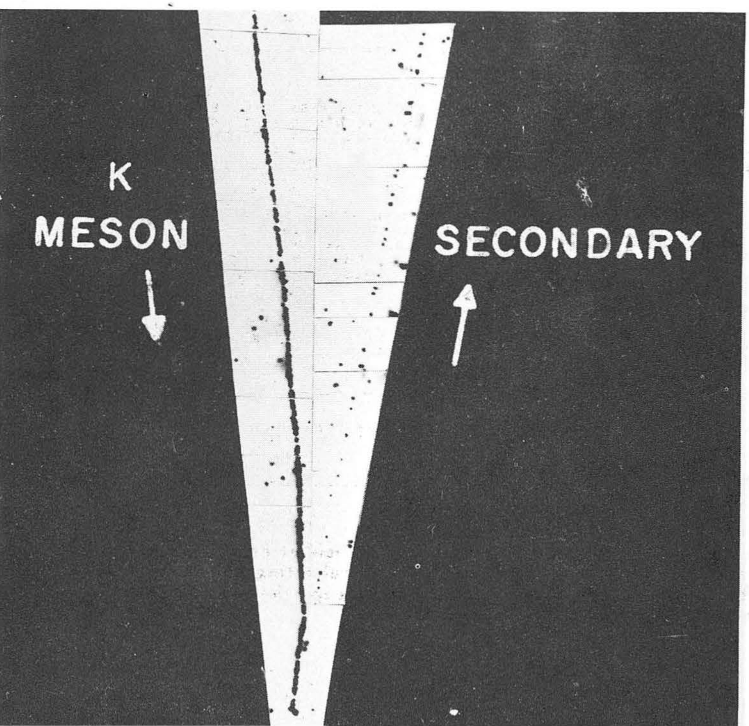
RESEARCH WITH THE BEVATRON

At the present time research with the bevatron is being devoted to the generation of nuclear particles by the bombardment of various elements with the proton beam and to their identification and study, and to nuclear chemical investigations of the mechanisms of very high energy nuclear reactions. Attention is being focused especially on mesons created in these high-energy collisions. Mesons are short-lived particles, first discovered in cosmic rays, that are found only when high-energy particles interact with nuclei. They are intimately involved with the powerful forces that hold nuclei together and are responsible, therefore, for the ultimate form and order of the physical universe.

With the energies available with the bevatron, it is possible to create under laboratory conditions various types of intermediate and heavy mesons previously found only in cosmic rays, where because of their feeble intensity and wide range of energy they are very difficult to use in precise experiments. With the completion of the 184-inch cyclotron it was possible for the first time to create mesons artificially, but only light mesons. The bevatron now extends the spectrum of laboratory mesons available to the experimenter and brings him closer to an understanding of their nature as well as of the interrelationships of mesons and their association with nuclear forces.

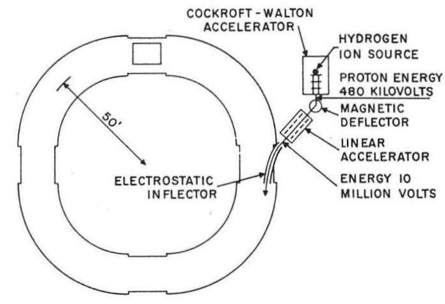


Right: Multiple meson production. The incoming π^-- meson strikes hydrogen nucleus producing a pair of mesons.



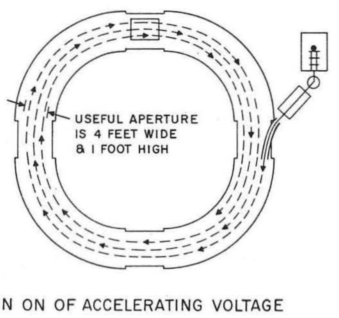
Left: Photomicrograph of a K-meson decay. The K-meson comes in from the top left and stops. Then it decays into a high-energy secondary particle which goes off toward the top right. K-mesons are rare heavy mesons. They are produced artificially only by such extremely powerful machines as the bevatron. The study of these mesons is one of the most interesting researches being carried out in the Radiation Laboratory. Event found and analyzed by Dr. H. Heckman. Photomicrograph by R. Michaelis.

HOW THE BEVATRON WORKS



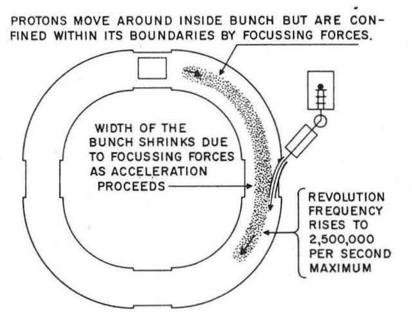
INJECTOR

Protons from a hydrogen ion source are accelerated in two stages and inflected into the bevatron at one of the straight sections.



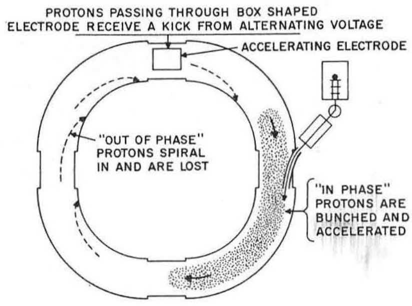
TURN ON OF ACCELERATING VOLTAGE

A voltage on an accelerating electrode alternating at the proton revolution frequency gives a kick of one to two kilovolts per revolution to part of the injected beam.



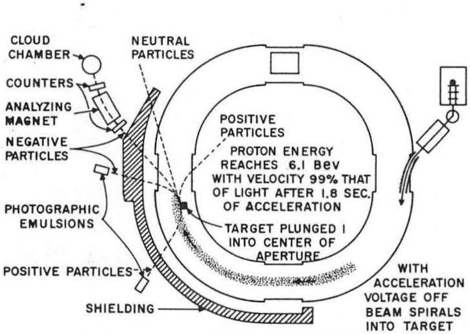
ACCELERATION

As the magnetic field strength rises the frequency of the accelerating voltage increases at a rate which keeps the beam centered in the aperture.



INJECTION INTO BEVATRON

In the low magnetic field of the bevatron at injection the protons circulate at 380,000 revolutions per second, spiraling inward as the field strength increases.



USE OF BEAM FOR EXPERIMENTS

The accelerated beam strikes one of several possible targets producing the nuclear events studied by the physicists and chemists.

Bevatron Statistics

Proton Beam

Maximum proton energy	6.1 Bev
Acceleration time	1.8 seconds
Pulses per minute	5
Number of revolutions to full energy	4 million
Distance traveled by protons	300,000 miles
Number of protons accelerated to 5.7 Bev (per pulse)	10 billion

Injection System

Beam produced by Cockcroft-Walton accelerator	3 ma at 480 kev
Energy produced by linear accelerator	10 Mev
Protons injected into bevatron (per pulse)	300 billion

Magnet and Magnet Power Supply

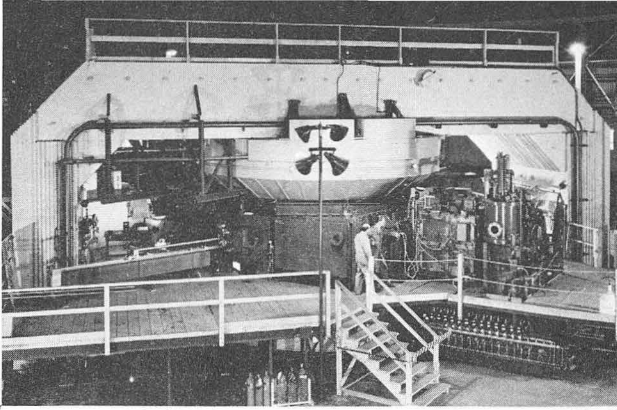
Weight of magnet	10,000 tons
Radius of proton orbit	50 feet
Length of straight sections	20 feet
Cross section of beam aperture	1 ft by 4 ft
Maximum energy stored in magnet	20 kilowatt-hours
Peak power input to magnet	100,000 kilowatts
Average power load	5,000 kilowatts
Maximum magnet current	8,000 amps
Maximum magnet voltage	16,000 volts

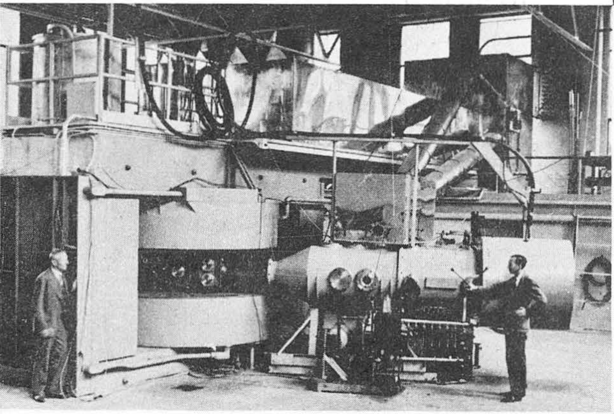
Accelerating System

Frequency at injection	380 kilocycles
Maximum frequency	2,500 kilocycles
Radiofrequency power	30 kilowatts at 20 kilovolts

184-INCH SYNCHROCYCLOTRON

Particles	Energy	Current (av)
Protons	350 Mev	0.75 μa
Deuterons	195 Mev	0.75 μa
Alpha particles	390 Mev	0.1 μa
Magnet		
Pole diameter	184 in.	
Weight	4300 tons	
Power	750 kw	
Oscillator		
Power input (av)	8.5-21 kw	
First Operation	Nov. 1946	



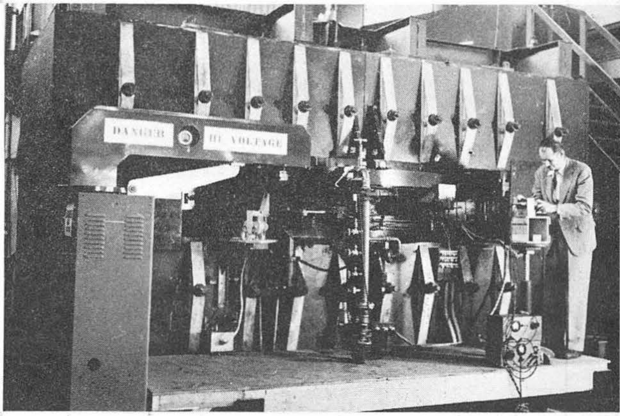


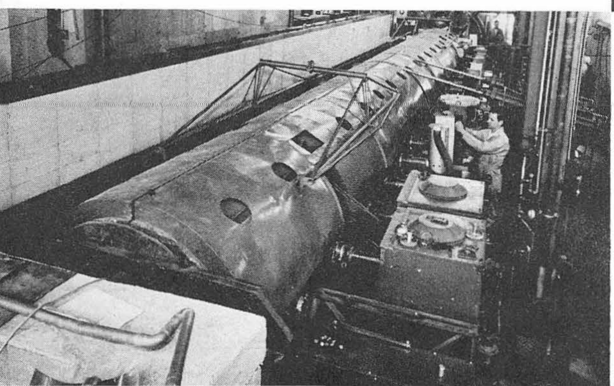
60-INCH CYCLOTRON

Particles	Energy	Current (av)
Protons	10 Mev	30 μa
Deuterons	20 Mev	40 μa
Alpha particles	40 Mev	10 μa
Magnet		
Pole diameter	72 in.	
Weight	220 tons	
Power	76 kw	
Oscillator		
Power input	75-90 kw	
First Operation	June 1939	

SYNCHROTRON

Particles	Energy	Current (av)
Electrons	335 Mev	10^8 electrons/pulse
Magnet		
Pole diameter	90 in.	
Weight	137 tons	
Power (av)	62 kw	
Oscillator		
Power input	10 kw	
Frequency range	44.6-50.4 Mc	
First Operation	Dec. 1948	





LINEAR ACCELERATOR

Particles	Energy	Current (av)
Protons	32 Mev	0.08 μa
Tank		
Length	41 ft.	
Diameter	49 in.	
Weight	8 tons	
No. of drift tubes	47	
Operation		
Frequency	203 Mc	
Rf energy storage	116 joules	
First Operation	Nov. 1947	

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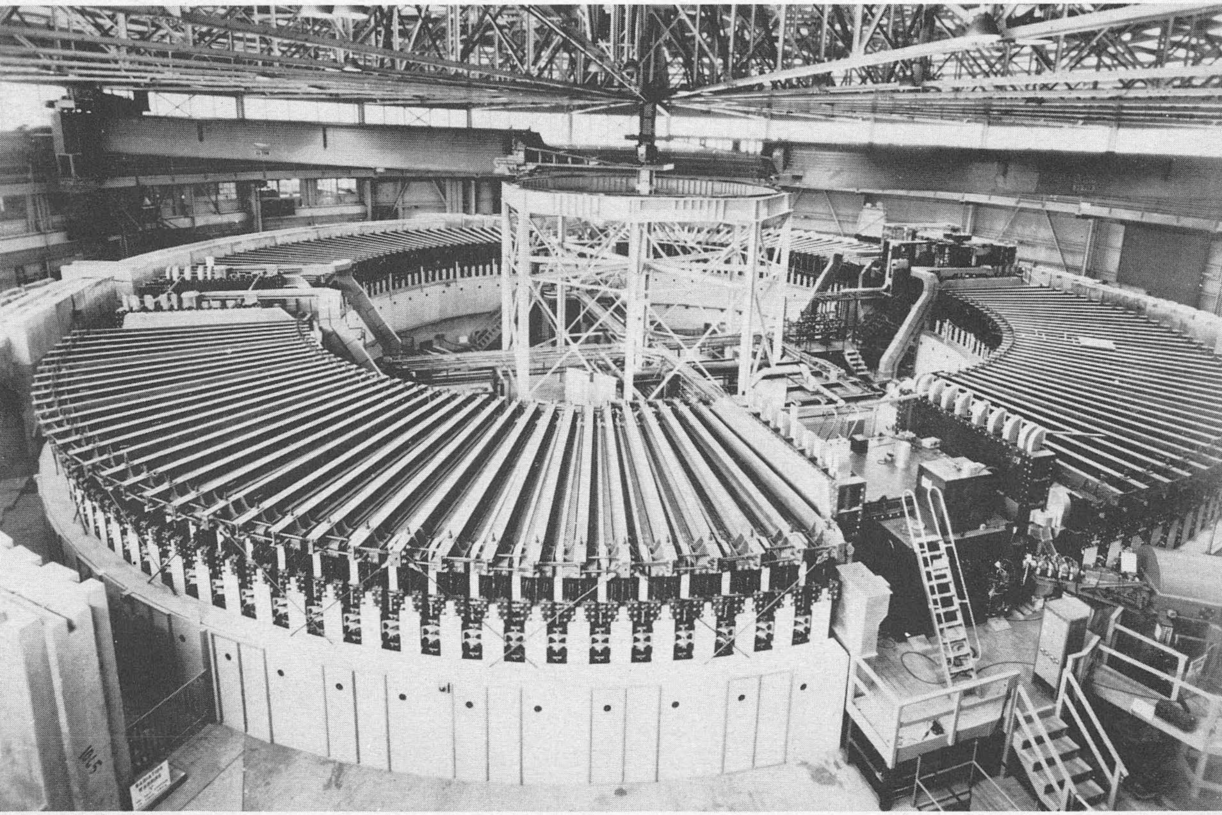

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In a time of less than two seconds the protons have circled the accelerating chamber approximately 4,000,000 times and have reached an energy of 6.2 billion electron volts (6.2 Bev). To hold them to their orbits, the magnetic field must increase to 15,500 gauss in this same period. By the end of the acceleration a pulse containing approximately 10^{10} protons of maximum energy has been produced; then the cycle starts over. There are 10 pulses per minute.

On pages 6 and 7 are diagrams illustrating how the Bevatron works and some data on its size and operation.

RESEARCH WITH THE BEVATRON

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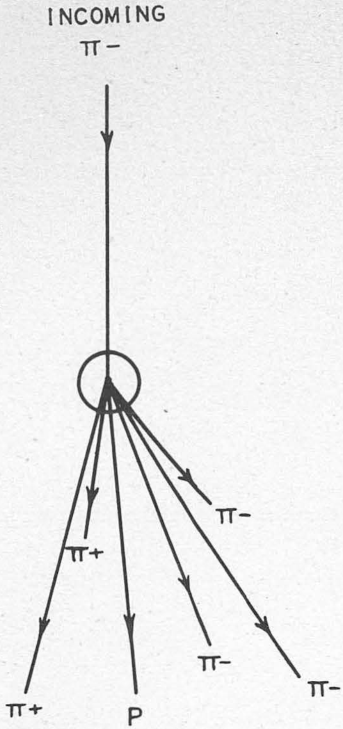
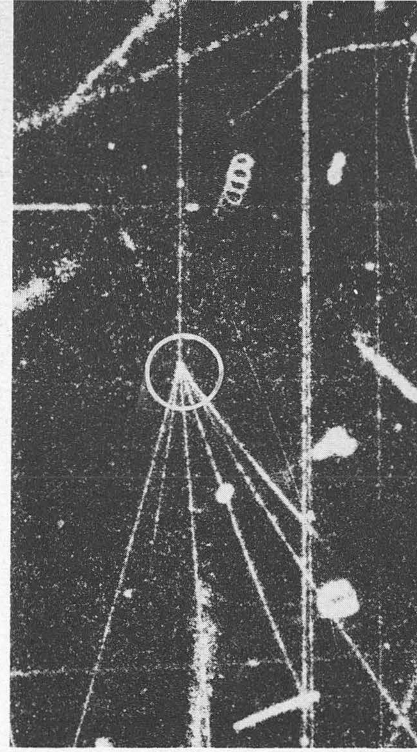
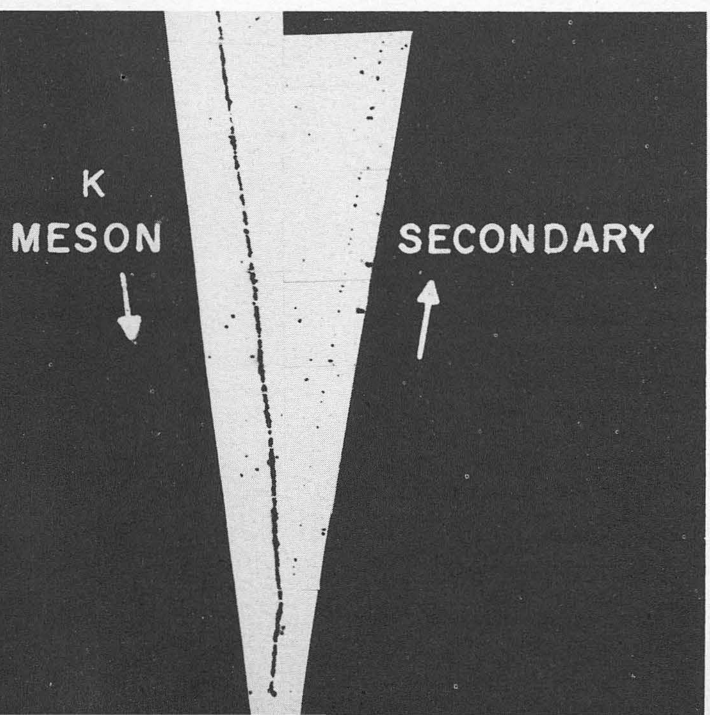


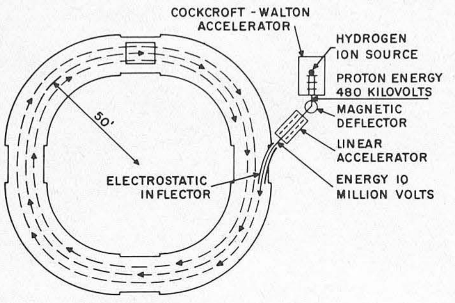


Right: Multiple meson production. The incoming π-meson strikes hydrogen nucleus, resulting in 5 mesons and 1 proton.



Left: Photomicrograph of a K meson decay. The K meson comes in from the top left and stops. Then it decays into a high-energy secondary particle which goes off toward the top right. K mesons are rare heavy mesons. They are produced artificially only by such extremely powerful machines as the Bevatron. The study of these mesons is one of the most interesting researches being carried out in the Radiation Laboratory.

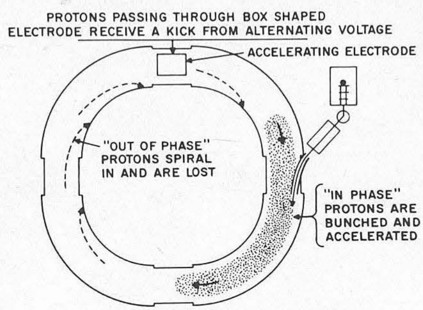
THE BEVATRON CYCLE



INJECTION

Protons from a hydrogen ion source are accelerated in two stages and inflected into the Bevatron at one of the straight sections.

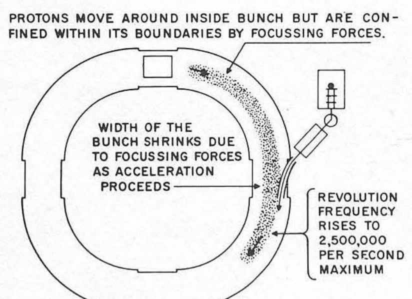
2



START OF ACCELERATION

A voltage on an accelerating electrode alternating at the proton revolution frequency gives a kick of one to two kilovolts per revolution to part of the injected beam.

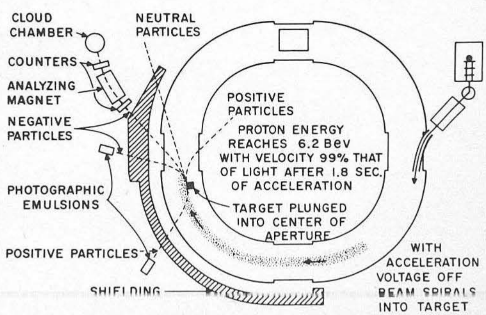
3



ACCELERATION

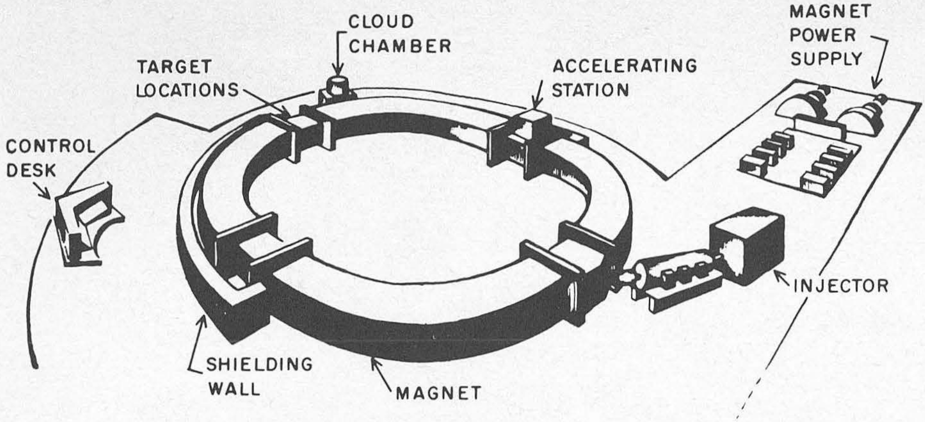
As the magnetic field strength rises, the frequency of the accelerating voltage increases at a rate which keeps the beam centered in the aperture.

4



USE OF BEAM FOR EXPERIMENTS

The accelerated beam strikes one of several possible targets producing the nuclear events studied by the physicists and chemists.



BEVATRON STATISTICS

PROTON BEAM

Maximum proton energy	6.2 Bev
Acceleration time	1.8 seconds
Pulses per minute	10
Number of revolutions to full energy	4 million
Distance traveled by protons	300,000 miles
Number of protons accelerated to 6.2 Bev (per pulse)	20 billion

INJECTION SYSTEM

Beam produced by Cockcroft-Walton accelerator	0.48 Mev
Energy produced by linear accelerator	10 Mev
Protons injected into bevatron (per pulse)	600 billion

MAGNET AND MAGNET POWER SUPPLY

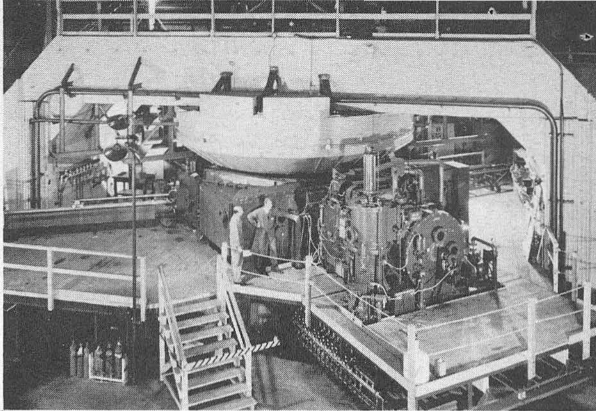
Weight of magnet	10,000 tons
Radius of proton orbit	50 feet
Length of straight sections	20 feet
Cross section of beam aperture	1 foot by 4 feet
Maximum energy stored in magnet	20 kilowatt-hours
Peak power input to magnet	100,000 kilowatts
Average power load	5,000 kilowatts
Maximum magnet current	8,300 amperes
Maximum magnet voltage	16,000 volts

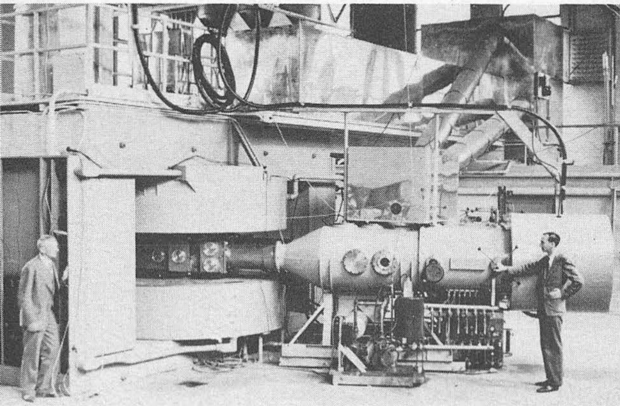
ACCELERATING SYSTEM

Frequency at injection	360 kilocycles
Maximum frequency	2,500 kilocycles
Radiofrequency power	30 kilowatts at 20 kilovolts

184-INCH SYNCHROCYCLOTRON

Particles	Energy	Current (avg)
Protons	350 Mev	0.75 μa
Deuterons	195 Mev	0.75 μa
Alpha particles	390 Mev	0.1 μa
Magnet		
Pole diameter	184 in.	
Weight	4300 tons	
Power	750 kw	
Oscillator		
Power input (avg)	8.5-21 kw	
First Operation	**Nov. 1946**	





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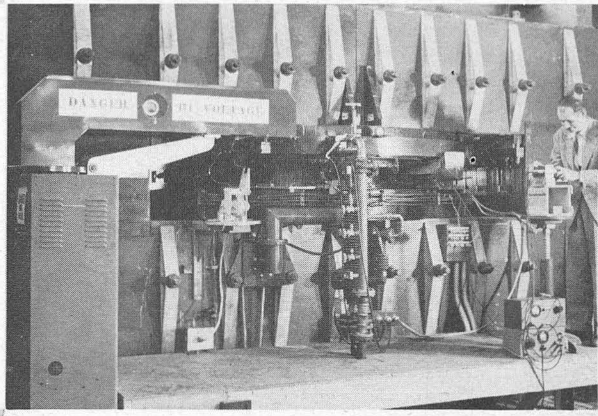
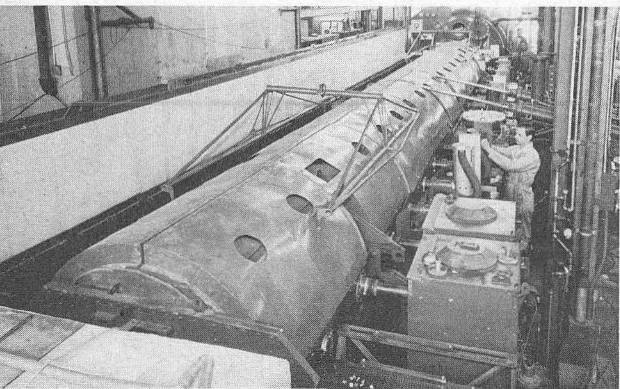
Particles	Energy	Current (avg)
Protons	10 Mev	30 μa
Deuterons	20 Mev	40 μa
Alpha particles	40 Mev	10 μa
Magnet		
Pole diameter	72 in.	
Weight	220 tons	
Power	76 kw	
Oscillator		
Power input	75-90 kw	
First Operation	**June 1939**	

SYNCHROTRON

Particles	Energy	Current (avg)
Electrons	335 Mev	10^8 electrons/pulse
Magnet		
Pole diameter	90 in.	
Weight	137 tons	
Power (avg)	62 kw	
Oscillator		
Power input	10 kw	
Frequency	47.7 Mc	
First Operation	**Dec. 1948**	





LINEAR ACCELERATOR

Particles	Energy	Current (avg)
Protons	32 Mev	0.08 μa
Tank		
Length	41 ft.	
Diameter	49 in.	
Weight	8 tons	
No. of drift tubes	47	
Operation		
Frequency	203 Mc	
Rf energy storage	116 joules	
First Operation	**Nov. 1947**	