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ROBERT RATHBUN WILSON
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A Biographical Memoir by

BOYCE D. MCDANIEL AND ALBERT SILVERMAN

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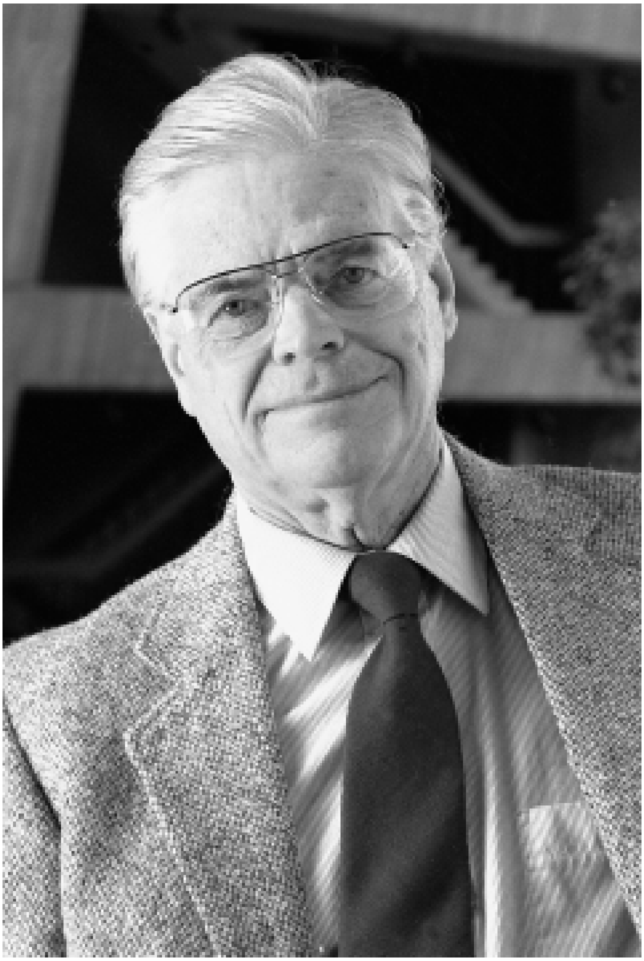

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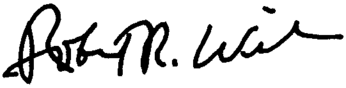

ROBERT RATHBUN WILSON

March 4, 1915–January 16, 2000

BY BOYCE D. MCDANIEL AND ALBERT SILVERMAN

ROBERT RATHBUN WILSON was one of the most important figures in accelerator development and research since Ernest Lawrence. He was the driving force for the creation of two of the four world-class high-energy physics laboratories in the United States: the Cornell Laboratory of Nuclear Studies and Fermilab, which houses the world's highest-energy accelerator—initially the 500-GeV proton synchrotron and since 1990 the tevatron, the world's first high-energy superconducting magnet synchrotron.

A brief review of his career cannot begin to describe his central role in high-energy experimental physics. His insistence on bolder, more compact, and economical design, seen clearly in the accelerators he built at Cornell, influenced the design of most modern accelerators, and his development of the first superconducting magnet accelerator at Fermilab made possible both technically and economically the very-high-energy accelerators now under construction.

Wilson was an inspiring leader. Each new project was the beginning of an adventure, a cause for celebration. The more challenging the project, the more exuberantly he embraced it. His attitude was contagious, and his colleagues responded with their very best efforts.

EARLY DAYS

Wilson was born on March 4, 1914, in frontier Wyoming, the son of Platt and Edith Rathbun Wilson. His mother's family were pioneer ranchers, and Wilson spent much of his early youth on the cattle ranches of his relatives in the vicinity. When he was eight years old, his parents separated and Robert attended the Todd school in Woodstock, Illinois, for several years. It was here that his interest in mechanics became pronounced enough for him to be dubbed "The Inventor." During his primary and secondary education he changed schools almost every year. In spite of this frequently interrupted educational career he set up a rudimentary laboratory where he experimented with vacuum phenomena using high vacuum pumps of his own design and construction.

Wilson was admitted to the University of California in Berkeley in 1932 and received his A.B. degree cum laude in 1936. During his junior year he began research under the direction of E. O. Lawrence. His first work was in the field of gaseous discharge, where he developed a new method of studying the time lag of spark discharges, a work of considerable importance that was published in *Physical Review* during his senior year.

Wilson continued his studies under Lawrence as a graduate student. Among the four papers he published as a graduate student were the first theoretical analysis of the stability of cyclotron orbits, which he verified experimentally, and a paper on the theory of the cyclotron. During his graduate career he made important contributions to the development of the cyclotron as a useful tool in the study of the atomic nucleus; for example, a vacuum sliding seal so that material, such as targets, could be inserted into the vacuum chamber without losing the vacuum. In 1940 he received his doctor's degree.

THE WAR YEARS

In 1940 Wilson married Jane Inez Scheyer of San Francisco, accepted an appointment at Princeton as instructor, and very soon found himself involved in the scientific war effort that was then developing. He collaborated with Fermi and Anderson in some experiments preliminary to the production of a chain reaction. In the fall of 1941 he invented an electromagnetic method for separating the isotopes of uranium and led a group of about 50 scientists and technicians at Princeton in developing this technique.

Early in 1943 the work on the separation of uranium isotopes was limited to those methods that were ready for production. The work at Princeton was terminated, and Wilson was asked to set up a cyclotron laboratory at the new Los Alamos laboratory. He and some of his Princeton staff moved the Harvard cyclotron to the new site and began to study the properties of the fission process. At Los Alamos he was the leader of the Cyclotron Group, and in the summer of 1944 Oppenheimer appointed him to head the Physics Research Division, which was responsible for experimental nuclear research and later for nuclear measurements that were made during the test of the first atomic bomb.

Toward the end of the war Wilson worked effectively for civilian control of atomic energy. He played a leading role in the formation of the Federation of Atomic Scientists, became it’s chairman in 1946, and later served a term as a member of its council and a second term as chairman.

In the fall of 1946 Wilson accepted an associate professorship at Harvard. He spent the first eight months of 1946 at Berkeley, where he designed a 150-MeV cyclotron for Harvard. His stay at Harvard was short, for in the winter of 1947 he went to Ithaca to become the director of the new Laboratory of Nuclear Studies and professor of physics at

Cornell University. He remained in that position until 1967, when he left Cornell to assume the directorship of the National Accelerator Laboratory, now Fermilab, in Batavia, Illinois.

THE CORNELL YEARS

During Wilson's tenure at Cornell he and his colleagues built four electron synchrotrons, each with unique physics capability. In 1948, shortly before the first synchrotron began to operate, he described in his yearly report to the Office of Naval Research what he thought the research program would be:

> The most important problems of nuclear physics, to our minds are: What are the elementary particles of which nuclei are made and what is the nature of the forces that hold these particles together? A more general but connected problem concerns the general expression of electrical laws at such high energies as will be produced by our synchrotron. Our experiments are planned to attack all three problems. Thus we hope to produce artificial mesons which are supposedly elementary particles and to study the interactions of these mesons with nuclei. Further, we shall explore the electrical interactions of high energy electrons with electrons and protons in search of evidence pointing to a correct theory of electricity at high energy.

Wilson's vision about future research was right on target. One would be hard put to improve on it today. It is the statement of a physicist with a very clear notion of why he was building the accelerator and where he was going. He built accelerators because they were the best instruments for doing the physics he wanted to do. No one was more aware of the technical subtlety of accelerators, no one more ingenious in practical design, no one paid more attention to their aesthetic qualities (he thought of accelerator builders as the contemporary equivalent of the builders of the great cathedrals in France and Italy), but it was the physics potential that came first. And the clear ideas he had about the physics he hoped to do is amply demonstrated in the almost prophetic statement quoted above.

For some 20 years as director of the Laboratory of Nuclear Studies Bob remained deeply embedded in the physics program, both as mentor and experimenter. He did important experiments in pi-meson photo production, including the first observation of the second nucleon excited state and published an analysis of its properties; he did the first measurements of the photo-production of strange particles; he pioneered a class of experiments using the circulating synchrotron beam and with this technique did fundamental work on the structure of neutrons and protons, extending the pioneering work of Hofstader at Stanford.

The first synchrotron, at 300 MeV, was designed and partly constructed before Wilson arrived at Cornell. It was a very productive machine, but by 1952 it was clear that the physics was urgently calling for higher energy and Bob initiated the construction of a 1-GeV synchrotron. Here is how Bob described his proposal in his 1953 annual report to the Office of Naval Research.

> The Laboratory has indulged itself in some high adventure. A new synchrotron has been designed which is to give over a billion electron volts of energy. The design is highly controversial in that the new machine is exceedingly small and cheap for what it will do, hence there is considerable risk that it may not work at all. On the other hand, if we are successful, we shall have the largest electron accelerator in the world and new areas of research will be opened to us. . . .

This annual report tells us much about Bob as an accelerator builder. It really was a great adventure for the reasons enumerated, made even more adventurous by switching in midstream to the just-published strong-focusing design of Courant, Snyder, and Livingston. What is also revealing is the candor of the proposal. There was no guarantee of success, only the guarantee of a scientifically exciting project worth the risk. Despite Bob's warning, the 1.4-GeV machine was very successful. Among the physics contributions were sensitive tests of quantum electrodynamics (QED) at short distances; discovery of the second nucleon resonance; first measurements of K-meson and rho-meson photo production; and precise measurements of nucleon structure. It was the first operating strong-focusing synchrotron and its design paved the way to more compact, less expensive accelerators. It should be noted that, characteristically, Bob had a fallback position for the riskiest aspect. The magnet was designed so that the pole pieces could be changed rather easily between strong-focusing and a conventional weak-focusing design. Bob was prepared to "climb out on a limb" if the reward was worth the risk, but he provided a safety net where he could.

The last machine that Bob built at Cornell was the 12-GeV synchrotron. This was the first accelerator to have the entire magnet evacuated so that it was not necessary to insert a separate vacuum chamber inside the magnet aperture. This made it possible to reduce the vertical magnet aperture to 1 inch, simplifying the magnet construction and reducing the power demands. This idea was subsequently adopted for the Fermilab booster accelerator. After about seven years of fruitful physics, devoted largely to QED studies at small distances, properties of the vector mesons, various tests of quark theory, and a big emphasis on the inelastic scattering of electrons, the 12-GeV synchrotron retired to a useful future as the injector for the Cornell electron storage ring, the electron-positron collider built between 1977 and 1999, and still serves that purpose.

In the 1940s and 1950s most of the accelerators were built at universities. There were perhaps 15 universities that had front-line accelerators. The only university for which this is true today is Cornell, which has endured as an important center of experimental high-energy research in this age of giant national and international laboratories, because it has always had an accelerator with unique physics capability built for a modest price. Wilson insisted on this during his tenure as director, and the two subsequent directors, B. D. McDaniel and K. Berkelman, continued in this “Cornell style.”

FERMILAB

In 1967, after completing the 12-GeV synchrotron, Bob left Cornell to become the director of the new National Accelerator Laboratory (now Fermilab) in Batavia, Illinois. Wilson’s performance at Fermilab was remarkable. Starting on a “green field” site with no staff, he began the job of building the most ambitious accelerator project ever undertaken up to that time. In addition to the challenge of building a cascade of large accelerators at a virgin site in less than five years Wilson promised to double the energy of the accelerator over the original proposal without an increase in cost. In fact this was accomplished at a 30 percent lower cost than the first proposal for the facility. He was able to do that primarily by redesigning the magnetic structures and lattice. This meant he could build the magnets with smaller aperture and higher magnetic fields, thereby doubling the energy of the protons circulating in the same size tunnel. This approach was later adopted by the European Organization for Nuclear Research (CERN) for the super proton synchrotron. Despite a serious setback, which required repairing a large fraction of the magnets because of insulation failure, the accelerator was completed on time and under budget. The achievement of higher energy and more physics reach at the same cost are hallmarks of Wilson’s career, appearing bold and imaginative when proposed and often considered risky and unrealistic. The fact that most of these principles were adopted in subsequent accelerators is further tribute to Wilson's vision and courage.

Wilson had a number of very positive principles having to do with construction projects. One was that there are certain design parameters that control the major costs. For example, in accelerator construction the magnetic aperture is likely to be the most sensitive cost-controlling factor. The amount of steel, copper, power, power handling equipment, and building costs all depend sensitively on this factor. He also believed that to build cheaply it was necessary to build rapidly. Rapid construction maintains excitement and esprit de corps, while slow construction runs up costs. He believed that it was essential to complete all those parts that could be made functional at the earliest possible time, in order that performance tests could be performed to confirm the validity of design and construction. He also felt that a highly engineered design was likely to end as being an over-design and in the end might be a faulty design requiring further modification anyhow. He preferred to make a design without a lot of safety factors, taking the risk that modification might be required later. He believed that, with the appropriate consideration for back-up provisions, this saved time and, in the long run, money.

Wilson followed these principles in designing the Fermilab accelerator. In his first design study he reduced the estimated time to seven years, but as construction proceeded rapidly he reduced the official schedule to six years. He had also set an internal target for the accelerator staff of completion in only five years. This made it possible to complete the facility within the official schedule in spite of major problems with the guide field magnets. The project was finished under budget and fully operating within six years of its start.

In addition to the technical success of the original accelerator Fermilab was also designed with a grace and beauty that makes it unique among high-energy physics laboratories. This fact, attested to by a number of prizes awarded for its architecture, shows the other side of Wilson: The artist who believed art and science should blend to form a harmonious whole that not only benefits scientific research and society but also extends its culture. This concern of Wilson is eloquently expressed in his colloquy with Senator John Pastore in testimony before the Congressional Joint Committee on Atomic Energy on April 17, 1969.

Senator Pastore: “Is there anything connected with the hopes of this accelerator that in any way involves the security of the country?”

Robert Wilson: “No sir, I don’t believe so.”

Pastore: “Nothing at all?”

Wilson: “Nothing at all.

Pastore: “It has no value in that respect?

Wilson: “It has only to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with are we good painters, good sculptures, great poets? I mean all the things we really venerate in our country and are patriotic about. It has nothing to do directly with defending our country except to make it worth defending.”

Fortunately, during the construction of the Fermilab accelerator tunnel adequate space had been provided for flexibility. This foresight was rewarded some years later with the construction in the same tunnel of the world's first superconducting collider at an energy of 2 TeV. At this writing that is still about twice the energy of any other operating accelerator.

The tevatron undertaking was vintage Wilson. The accelerator required approximately 1,000 very accurate and reliable superconducting magnets to guide the circulating beams. It required an enormous leap in superconducting technology. Wilson provided the vision and leadership and devoted personal involvement during the several years of difficult R&D required to establish the mass-production technology and to make it possible for a remarkably low cost. The tevatron demonstrated the feasibility of large accelerators built with superconducting magnets and paved the way for HERA in Hamburg, Germany, the relativistic heavy ion collider at Brookhaven, the ill-fated Superconducting Super Collider in the United States, and the large hadron collider now under construction at CERN. Without the superconducting technology the capital and operating costs for multi-TeV storage rings would be prohibitive. Construction of the tevatron led to a large expansion in commercial production of superconducting cable, now used extensively in magnetic resonance imaging.

It must be noted that Wilson was unable to lead personally the tevatron construction to completion. Near the end of the R&D period Wilson asked the Department of Energy for a higher level of funding in order that the development could proceed at a fast pace and at the same time support the heavy financial burden of fully utilizing the existing 400-GeV accelerator for research. It was typical of Bob's driving determination that he handed in his resignation as a matter of principle to protest against what he considered to be under-funding of the laboratory. Somewhat later the support level was increased, but unfortunately by that time it was too late. Subsequently Leon Lederman was named director; then he, together with the Wilson-trained staff, brought the Wilson-inspired tevatron into operation. After his resignation from Fermilab Wilson held professorships at the University of Chicago and Columbia University and retired in 1983.

Wilson's influence was enormously important to the physics program and to the results achieved at Fermilab, the two most important being the discovery of the b-quark and the top quark. This third and heaviest family of quarks "belongs" to Fermilab. Running at the highest possible machine energy was crucial to these discoveries. It was Wilson's insistence on operating the main ring at the highest possible energy (in the face of considerable opposition from some experimenters who wanted to reduce the energy to improve the momentary reliability of the accelerator) that made possible the discovery of the b-quark. For Wilson, energy was the key to new discovery. This was, of course, also the case for the much heavier top quark, for which the full energy of the tevatron was required.

HADRON CANCER THERAPY

A paper of Wilson's published in the journal *Radiology* in 1946 and entitled "Radiological Use of Fast Protons" has assumed great importance. In 1941 Wilson had made accurate measurements of the range and energy deposition of fast protons as they traversed matter. He observed that protons deposit most of their energy near the end of their path in what is called the Bragg peak. There was nothing unexpected about this measurement, but it led him to a happy and far-reaching idea—to use protons for cancer therapy. Wilson noted that, because of the Bragg peak and by carefully controlling the energy of a proton beam, most of its energy could be deposited in a cancerous tumor inside the body.

This is in stark contrast with radiation treatment by electron or photon beams obtained from radioisotopes like cobalt, which attack healthy and cancerous tissues indiscriminately. The first facility for this therapy was at the Harvard cyclotron. Subsequently a similar facility was installed at Fermilab. Proton beams have now been used successfully for cancer therapy at a number of accelerators. With the advent of magnetic resonance imaging and positron emission tomography, which can determine the positions of cancerous tumors with high precision, there has been a large increase in interest in this therapy, and single-purpose hospital-based proton accelerators have been built for hadron therapy in many different countries. Wilson was honored for his pioneering work in this area at an international conference held at CERN in 1996.

AWARDS AND HONORS

Wilson was awarded honorary degrees from Notre Dame University, Harvard University, University of Bonn, and Wesleyan University. Among the many other honors he received were the Elliot Cresson Medal from the Franklin Institute, the National Medal of Science, the Enrico Fermi award, the Wright prize, the del Regato Medal, and the Gemant award. He was a member of the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. In 1985 he was elected to the presidency of the American Physical Society.

Throughout the course of his life, in everything he did, Wilson's effervescent personality came through. He was a man filled with exciting ideas; inventions; interest in art, humanities, and nature; and high ideals and moral principles. Some examples of these interests include the restoration of the grasses of the Great Plains and the buffalo herds on the Fermilab site; his artistic stamp on the architecture at Fermilab; his personal sculptures at the laboratory and in his own home; his role in promoting international cooperation as one of the organizers of the International Committee on Future Accelerators; his very effective affirmative action program at Fermilab; his commitment to the Federation of Atomic Scientists and the American Physical Society and his long-time work toward proton therapy; his determination never to give up a difficult recovery attempt in a squash game; and dozens of other examples. Wilson was truly a man who enjoyed living life to the fullest.

Wilson's legacy to high-energy physics and the laboratories he built survives his death. This feeling was eloquently expressed by Judy Jackson, director of public affairs at Fermilab, in a letter to Bob's son, Jonathon. She wrote,

> It is probably impossible to overstate his [Bob's] influence on Fermilab. I think most of the time institutional memories are rather short; even people who play important roles are forgotten surprisingly quickly. This is emphatically not the case for Fermilab and your father. One cannot spend a day, or an hour, without feeling his presence in the architecture, the prairie, the accelerators, and the attitude. For once it is no cliché to say he lives on; he really does.

WE WISH TO THANK Jane S. Wilson for much helpful information about Bob's work and life.

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