George Trilling

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A Biographical Memoir by Robert N. Cahn, Jonathan Dorfan, and Herbert Steiner

George Trilling was a leader of the international high-energy physics community from the days of cloud chambers to the time of the discovery of the Higgs boson at the Large Hadron Collider. From the time of his thesis work until the 1970s, his work focused on strange particles, whose properties revealed the central features of fundamental interactions, parity violation, CP violation, particle oscillations, and the quark model. He was co-leader of the SLAC-LBL collaboration that discovered the J/ψ charmed particles and the τ lepton. His exceptional understanding of physics and his widely appreciated wise counsel led to his being asked to provide leadership from early in his career through its later stages.

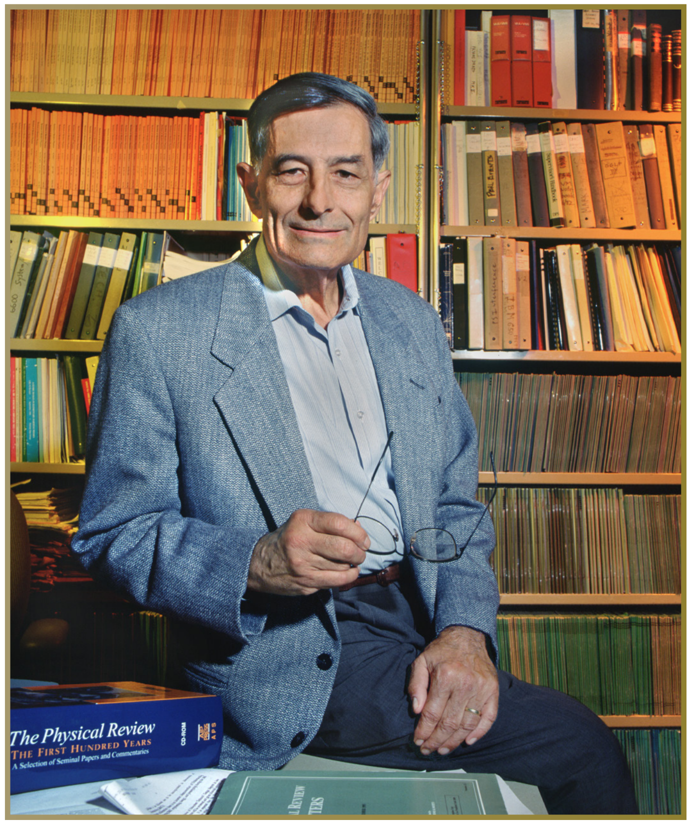

Figure 1 George Trilling. *Photo courtesy Lawrence Berkeley National Laboratory, © 2010 The Regents of the University of California, Lawrence Berkeley National Laboratory.*

Early Years and Arrival in the United States

Trilling recounted his earliest years in an unpublished memoir, upon which this memoir will rely in covering personal aspects for the period up to 1962. In 1930, he, his parents, older brother Charles, and paternal grandparents left Bialystok, fearing the situation for Jews in Poland. They settled into a comfortable life in Nice, France. He attended a lycée there and enjoyed family vacations in the Alps. He recalled, "During these summer travels, my father occasionally decided that I need more intellectual activity. He then assigned me a topic on which I had to write an essay. This activity had one useful outcome: I learned never, never to show someone anything that I had written unless I had first carefully reread it and, where needed, corrected any obvious error." Indeed, Trilling was known for his scrupulous editing of manuscripts and reports.

In 1940, as the war began, the family moved to Toulouse, farther from the border with Italy. In the summer of that year, part of the family left from Biarritz, but George and his parents returned to Nice because the French would not allow his father, still of military age, to leave. By December, new arrangements allowed the three of them to reach Lisbon, Portugal, where they stayed for about two months. In March 1941, a flight on a large four-engine hydroplane took the Trilling family to Portuguese Guinea (now the African nation of Guinea-Bissau). The next day they arrived in Brazil. Stops in Trinidad and Puerto Rico followed before finally reaching New York. To obtain immigration visas, however, it was necessary to leave the United States, and so the family made a quick trip to Cuba and then back. After a summer and fall in Chicago, George and his parents moved to Pasadena, where his brother Charles was already an undergraduate at the California Institute of Technology (Caltech).

High School and College

Trilling attended LeConte Junior High School, named after University of California, Berkeley geology professor Joseph LeConte. Trillling's office for more than forty years was in Berkeley's LeConte Hall, named after John LeConte, Joseph's brother and fellow scientist and academician. Beginning in 1945, Trilling attended Hollywood High School and continued to do so even when the family moved to central Los Angeles. After just two and a half years of high school and not quite seventeen years old, Trilling was admitted to Caltech, where he won a full-tuition scholarship for his first year. Despite his preference for physics, Trilling majored in electrical engineering at the insistence of his father, who was skeptical of the financial future for a physicist. As in the case of Paul Dirac, this choice of major in no way hindered his development as a physicist, though as an engineering major Trilling told of "some less exciting course like surveying, in which students had to go to a dry river bed with transit and make maps of the surroundings." Despite being an undergraduate engineering student, Trilling began working with the research group of Carl Anderson, discoverer of the positron and the muon [Figure 1]. At the time, the actual leadership of the group came from Robert Leighton.

Cloud chambers were then the device of choice for observing reactions initiated by cosmic rays. The British team of George D. Rochester and Clifford C. Butler had observed two instances in which particles decayed with lifetimes on the scale of 10^{-9} to 10^{-10} seconds. What was remarkable was not their brevity but rather that they lived much, much longer than expected. These particles were evidently produced in strong interactions like those that bind protons and neutrons in the nucleus. If they were produced in strong interactions, why didn't they decay through strong interactions, which would dictate lifetimes on the order of 10^{-23} seconds?

This peculiar behavior led to the designation of a class of "strange particles." Trilling's research focused on them for the next two decades, a period during which strange particles played the central role in revealing key features of fundamental interactions: strangeness itself, particle oscillations, parity violation, SU(3) symmetry, the quark model, and CP violation.

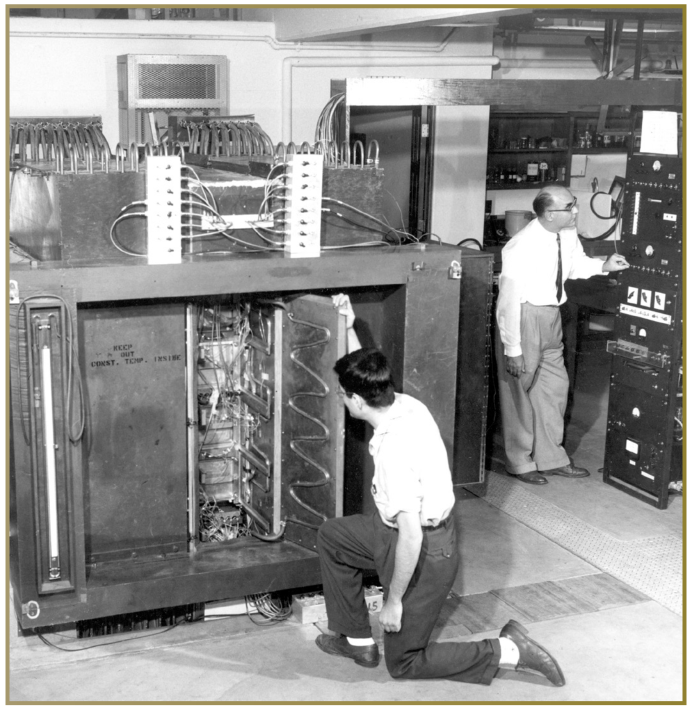

Figure 2 Trilling with Carl Anderson in the cloud chamber lab at Caltech. *Photo courtesy of Caltech Archives.*

Graduate School

Trilling continued at Caltech as a graduate student, finally now in physics. That Trilling was an exceptional graduate student was testified to by William Smythe, whose problems in his classic, Static and Dynamic Electricity, terrified students at that time the way that students over the past several decades have been terrified by those in John David Jackson's Classical Electrodynamics. In 1976, when recounting all his students who had gone on to win Nobel prizes, Smythe recalled that despite his not having won one himself, Trilling was "his all-time star achiever" with four perfect exam scores.

As a grad student, Trilling continued with the Anderson group, studying charged strange particles. When strange particles decayed in a cloud chamber, what appeared typically had the shape of a V. An incoming charged particle left a track that suddenly changed direction when the decay took place into a charged particle and an unseen neutral particle. An incoming neutral strange particle left no track until it decayed to two oppositely charged particles, again left the V signature. Thus prior to the development of the concept of strangeness by Murray Gell-Mann, these were known simply as V particles. Trilling's thesis was entitled "A Cloud Chamber Investigation of Charged V Particles." His first publication came prior to his thesis: in 1954, he was co-author with Victor van Lint, Anderson, and Leighton, in a measurement of the energy released in the decay of the Λ^0 to a proton and a π^-. In his thesis, whose results were published together with

Robert Leighton, a variety of decays with names - K, θ, τ – were observed. It was gradually understood that these were different decay outcomes of a single particle, K^+.

In the summer of 1955, at the age of twenty-four, Trilling received his Ph.D. from Caltech. A few weeks later, Trilling married Madeleine ("Maya") Monic, who had also been born in Poland. Maya had survived the war thanks to her Polish Catholic nanny, who passed her off as her own child. In the end, Maya was reunited in France with her mother, who had survived the war in a concentration camp. Eventually they ended up Beverly Hills. Maya and George met on a blind date in 1953 that led to a marriage of sixty-five years.

After his thesis work, Trilling stayed on for a year at Caltech, continuing his study of strange particles with the cloud chamber. Together with John Kadyk, Leighton, and Anderson, he published a study of some decays of neutral particles that appeared anomalous, not quite conforming to the established categories. Although their masses were consistent with that of the θ^0, other features were not. A detailed analysis indicated that these were evidence for a particle with a much longer lifetime than that of the θ^0 and fit the description of a particle postulated by Murray Gell-Mann and Abraham Pais. Similar results had been reported by other groups. The Gell-Mann-Pais scheme argued that two neutral particles, K^0 and its anti-particle K^0-bar, combined quantum-mechanically to make a short-lived K_S and a long-lived K_L.

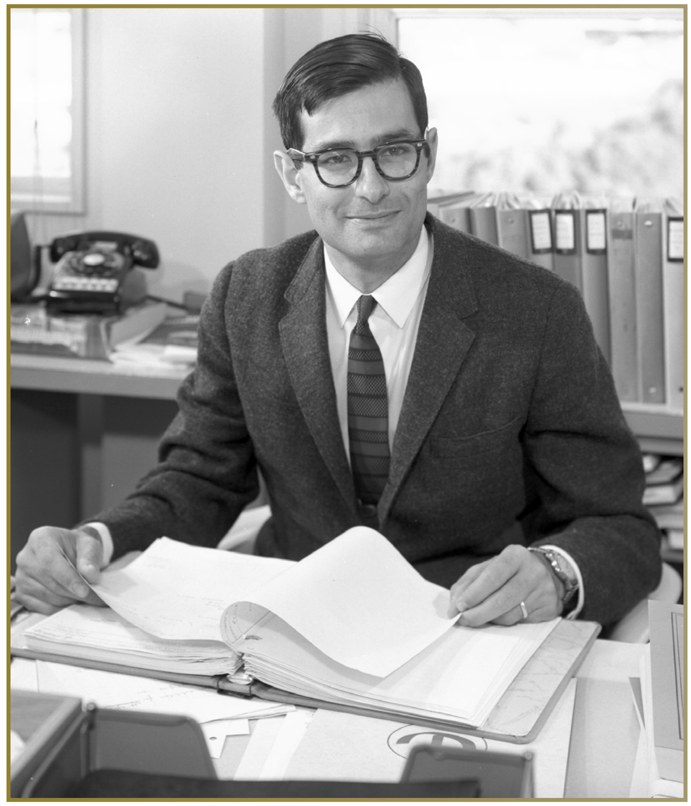

Figure 3 George Trilling at Berkeley, 1963. *Photo courtesy Lawrence Berkeley National Laboratory, © 2010 The Regents of the University of California, Lawrence Berkeley National Laboratory.*

MICHIGAN AND THE BUBBLE CHAMBER

The following year, Trilling accepted a position as an assistant professor at the University of Michigan, an offer that was particularly attractive because of the presence of Donald Glaser, inventor of the bubble chamber, which would supplant the cloud chamber as the instrument of choice for observing particle interactions. The bubble chamber was particularly suited for use at particle accelerators, which were themselves replacing cosmic rays as the primary source for the study of subnuclear particles.

Prior to moving to Ann Arbor, Trilling spent a year at the École Polytechnique in Paris on a Fulbright Fellowship, with the University of Michigan allowing this delay in his arrival there. In Paris, Trilling worked with another technique for observing particle collisions and decays: photographic emulsions. Like the cloud chamber, this too could not compete with the bubble chambers that were waiting when he returned to the United States in 1957.

At Ann Arbor, Trilling worked with Glaser's group, which included John Brown, Dan Sinclair, John Kadyk (who had also come from Caltech), and Jack Vander Velde. Together they built a liquid xenon bubble chamber. Liquid xenon was especially attractive as a medium because its high nuclear charge increased the likelihood that gamma rays arising from neutral pion decays could be observed when they were transformed into electron-positron pairs. In 1959, this team used their liquid xenon chamber to publish conclusive evidence that K_S could decay to a pair of neutral pions, which was expected since it was known to decay to a pair of charged pions. The ability of this bubble chamber to identify neutral pions efficiently also enabled the team to measure the decay Λ to $n\pi^0$ and show that the rate agreed with an empirical rule called "$\Delta I=1/2$," which refers to the half a unit of isospin change in non-leptonic weak decays.

BERKELEY

In 1960, Trilling left the University of Michigan for a position at the University of California, Berkeley, where Glaser had moved the previous year. Glaser's invention of the bubble chamber in 1952 led to its quick adoption in high-energy physics labs around the world. By March 1959, a 72-inch hydrogen bubble chamber, whose steel casting alone weighed nearly 3,000 kilograms, was operating at the Lawrence Radiation Laboratory (now Lawrence Berkeley National Laboratory). Shortly after the arrival of the Trillings in Berkeley, Glaser was awarded the Nobel Prize in Physics for his invention of the bubble chamber. Glaser then announced that his future research would be in biophysics, leaving Trilling as the senior member of the portion of the Michigan team that had moved to Berkeley. [Figure 3]

The direction of the group changed when it merged with a team headed by Gerson and Shula Goldhaber, which was using hydrogen bubble chambers rather than a heavy-liquid chamber. The new team, the Trilling-Goldhaber group, used a beam of positive K mesons with a new 25-inch bubble chamber. Before the completion of the new bubble chamber, data were obtained at Brookhaven's Alternating Gradient Synchrotron (AGS) with a pion beam. Whereas Trilling's previous work had examined particles decaying weakly and thus traversing a macroscopic distance before decaying, this work focused on resonances, particles that decayed in less than 10^{-20} seconds and whose existence could only be established by reconstructing their decay products and demonstrating they came from an object with a well-defined mass. The new 25-inch hydrogen bubble chamber was used in a novel fashion. A K^+ beam with a momentum of 800 MeV/c was directed to a target near the bubble chamber. The K_L beam that emerged was used as the source for collisions with the bubble chamber protons. Because the K_L contains both positive and negative strangeness, the data provided information on these two channels simultaneously.

The K^+ beam itself was used to study collisions that produced $K^0 p\ \pi^+$ or $K^+ p\ \pi^0$ and in particular final states that were "quasi-two-body," where one pair of particles formed a resonance. In this instance, there can be a π-p resonance or a K-π resonance. The data showed that these two final states interfered quantum mechanically.

The results that the Trilling-Goldhaber group published through 1967 included work for which Shula Goldhaber, who tragically died in 1965 during a trip to India, was a leading contributor. The Trilling-Goldhaber group remained highly productive for many years, its effectiveness benefitting greatly from the complementary talents of its two leaders: Gerson Goldhaber's intuitive sense of where the important physics lay and George Trilling's powerful analytical skills and leadership qualities.

In 1969, the Trilling-Goldhaber group using a π^+ beam with the 72-inch bubble chamber observed events in which $\pi^+\pi^-$ pairs had a preference of a combined mass between 760 MeV and 800 MeV. This feature was well known as the ρ resonance. In these data, however, there was a pronounced narrow dip near 783 MeV, the mass of another well-known resonance, ω. This was a clear indication of negative interference, but a surprise because the decay of ω was known to be to three pions. Two conservation laws of strong interactions, charge conjugation invariance and isospin invariance, determine these decay patterns: ρ to $\pi\pi$, ω to $\pi\pi\pi$. The interference showed that these rules were broken: some small fraction of the time, about 1.5%, ω does decay to $\pi\pi$. This is possible because isospin is not an exact conservation law, but is broken by electromagnetism and by the difference between the masses of the up and down quarks, though the latter was not known at the time.

Trilling's mastery of developments in theoretical particle physics was demonstrated when he published a sole-author paper in Physical Review Letters in 1970 that showed how the asymptotic cross-sections for scattering initiated by pions, kaons, protons, and their antiparticles could be estimated from the data available at that time. He showed that the results were consistent with the Pomeranchuk theorem, which stated that if the cross-sections became constant at high energy, then the total cross-sections for the scattering of a particle by a proton and by of its anti-particle by the proton would converge to the same asymptotic limit. Many years later, it became apparent that total cross-sections continue to grow with increasing energy, making the situation more complex.

The Trilling-Goldhaber group itself contributed to the cross-section data, often looking for new resonances using devices and analysis tools developed at the Lawrence Radiation Laboratory (the name was changed to Lawrence Berkeley Laboratory in 1971): the flying-spot digitizer, Franckenstein measuring projects, and analysis codes SIOUX and ARROW.

Berkeley Physics Department

Though only thirty years old when he joined the physics department, Trilling immediately impressed his colleagues with his deep understanding of physics and his low-key but highly effective organizational abilities. He quickly integrated himself into the activities of the department and was soon recognized as a very gifted and well-organized teacher in courses ranging from pre-med physics to graduate-level electricity and magnetism. His exceptional ability to see through to the heart of an issue, whether scientific or administrative, and to provide wise and persuasive guidance led to his becoming chair of the department at the age of just thirty-eight. Those talents were recognized by all who knew him and led in the same way to leadership roles in the national and international physics community for the rest of his life.

Being department chair at Berkeley from 1968 to 1972 was not an easy task as Berkeley was a primary center of the student anti-war movement. Leading a smoothly running physics department under such conditions was challenging, to say the least. The Vietnam War and racial strife made it difficult to focus on Newton or Einstein. Trilling succeeded in steering a sometimes sharply listing ship through the turmoil. One of the co-authors (RNC) can testify directly to the skill with which he handled the demands brought by the graduate students at that time.

Despite these challenges, Trilling continued his research and training of Ph.D. students. During his time in the Berkeley Physics Department, he was the thesis advisor for twelve students, many of whom went on to distinguished careers in academia and industry: Dante Amedei, Roger Bland, Robert Harr, John Hauptman, J. Frederick Kral, Jimmy MacNaughton, Mark Nelson, Peter Rowson, Heidi Schellman, Victor Seeger, Paul Sheldon, and Eric Vella.

As his chairmanship was coming to an end, his research turned to a new direction.

SLAC-LBL Collaboration

By 1972, the era of bubble chambers was waning. Trilling and Goldhaber were approached, as was their Berkeley colleague Willi Chinowsky, by Burton Richter and Martin Perl of the Stanford Linear Accelerator Center (SLAC), and they agreed to join in the construction of a detector for the Stanford Positron Electron Accelerating Ring (SPEAR). SPEAR collided electrons with positrons captured by running an electron beam into a material in which electron-positron pairs were produced. The Mark I detector had a novel design: it covered much of the 4π solid angle around the collision point. Although Trilling was at CERN during much of the construction of the detector, he brought a critical element to the experiment: analysis code that transformed measurements from the tracking chambers into identified and quantified charged tracks emanating from the collision vertex. This track reconstruction code and its track parameter errors became the worldwide standard for the emerging 4π detectors.

On November 11, 1974, the SLAC-LBL collaboration team was prepared to announce that over the weekend they had discovered a resonance in electron-position annihilation whose width was too small to measure directly because it was obscured by the energy spread of the colliding beams. Remarkably, equally astonishing results had been obtained in a totally different experimental setup by a team at Brookhaven led by Samuel Ting of MIT. The two simultaneous announcements profoundly affected the direction of particle physics. They strongly suggested that the new particle, dubbed the J/ψ, was made of a heavy quark-antiquark pair—the charm quark and its anti-particle—and at the same time made apparent that quarks weren't a mathematical fiction, but were concrete entities. This conjecture was cemented when, soon thereafter, the SLAC-LBL collaboration discovered a series of mesons comprised of a light quark and the purported charmed quark. Two years later, the collaboration made yet another Nobel-winning discovery, led by Martin Perl, which revealed a third charged lepton joining the electron and muon. [Figure 4]

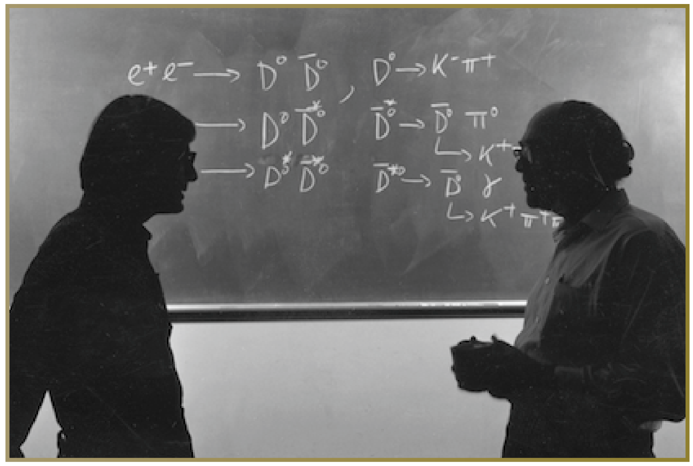

Figure 4 George Trilling (left) and Gerson Goldhaber discussing the decays of charmed particles. *Photo courtesy Lawrence Berkeley National Laboratory, © 2010 The Regents of the University of California, Lawrence Berkeley National Laboratory.*

The Mark I detector was succeeded by Mark II, which operated at SPEAR starting in 1977. A higher energy electron-positron collider, the Positron-Electron Project (PEP), was constructed as a collaboration of SLAC and LBL at SLAC, and the Mark II detector was moved there in 1979. With a center-of-mass energy of 29 GeV, PEP was able to study mesons containing the fifth quark, b. An important result in which Trilling played a key role was the measurement of the lifetime of mesons containing the b quark. The surprisingly long lifetime—near one-and-half picoseconds—allowed for the possibility of measuring CP violation in B meson decays at asymmetric colliders some years later.

The upgrade project for Mark II's third incarnation as a detector at the Stanford Linear Collider (SLC) was led by Trilling, Jonathan Dorfan, and Gary Feldman. SLC was a very ambitious program to reach an energy sufficient to study the Z boson, which was discovered at CERN's $Sp\bar{p}S$ collider in 1983. The SLC accelerated electrons and positrons in the same direction, then bent their paths around opposite curves until they collided head-on. This daring concept proved a significant challenge, and the intensity of the colliding beams fell well short of the design; notwithstanding this shortfall, the Mark II collaboration produced conclusive evidence that there were no more than three low-mass neutrinos. Ultimately, another detector collaboration, SLD, was able to do some unique measurements with polarized electron beams.

Leadership of the LBL Physics Division

From 1984 to 1987, Trilling served as director of the Physics Division of Lawrence Berkeley Laboratory. Having participated in the transition from the era of bubble chambers to that of electronic tracking detectors like the Mark I and Mark II, he oversaw the emergence of solid-state detectors, the technology that dominated efforts at Berkeley for the next forty years. Despite his lack of experience in this area, his keen judgment was critical to the development of silicon detectors, application-specific integrated circuits, and data-acquisition systems. These were applied to major efforts in both the Collider Detector at Fermilab (CDF) and DZero experiments at Fermilab.

Superconducting Supercollider

Following the SLC program, Trilling and Gerson Goldhaber went in different directions. Goldhaber joined a group studying supernovae, a project that led ultimately to the discovery that the Universe is expanding more and more rapidly. Trilling joined a group planning a detector for the Superconducting Super Collider (SSC). This was not Trilling's first involvement with the SSC. He had been a member of the initial SSC Board of Overseers starting in 1984 and continued to play an important role in the development of the project. Trilling became the spokesperson for the Solenoidal Detector Collaboration, one of the large detector collaborations that formed to make proposals for the SSC. Ultimately, two large detector proposals were supported: SDC and GEM, the latter headed by Barry Barish and Bill Willis. The end is well-known: Congress terminated the program in October 1993. Fortunately, much that had been learned was applied to the parallel project at CERN, which ultimately completed the Large Hadron Collider (LHC).

Large Hadron Collider at CERN

The compelling physics program contemplated for the SSC was fully appreciated at CERN, where the existing tunnel for the electron-positron collider LEP provided a very attractive opportunity to move quickly to a high-energy proton-proton collider. Although its 27-kilometer circumference would be less than one-third of that planned for the SSC, and correspondingly the beam energy would be roughly proportionally smaller, that might be compensated for by higher beam intensities. It was natural then that the physicists designing detectors for the SSC would turn their attention to CERN. The negotiation for U.S. participation in the LHC program was necessarily complex. The United States sought a major role, with its scientists comprising perhaps 25 percent of the total. But the United States was not a member of CERN and did not pay annual dues, which would have cost $250 million per year. Shortly after the termination of the SSC project, Trilling helped set up a meeting at CERN of leaders of the SSC projects, with participation from Canada and Japan as well as the United States. Throughout the roughly four years it took to resolve all the issues of U.S. participation in LHC, Trilling provided guidance essential to the ultimate success. In the end, the United States contributed significantly to both the accelerator and the LHC detectors, with participation from both the Department of Energy and the National Science Foundation. The Berkeley group that had worked on SDC joined the ATLAS experiment and brought its expertise in silicon and pixel detectors to that collaboration. Trilling is listed, fittingly, among the authors of the Higgs discovery paper by ATLAS.

A Revered and Beloved Educator and Leader

A recitation of Trilling's many research accomplishments fails to convey the esteem with which he was held by his collaborators and throughout the worldwide physics community. That he was elected to the position of president of the American Physical Society does reflect that esteem, but it was his personal qualities that made him stand out among his colleagues. George was always the colleague to whom one turned for wisdom, for wisdom in science, in research, and equally for wisdom in addressing challenges of a personal or political nature. He was a mentor to generations of younger physicists, a man of great integrity, and a benevolent and patient teacher who taught by example, rather than by fiat. The three of us have been fortunate to have been involved in several path-breaking experiments as well as some challenging administrative tasks during our careers, and George's influence helped us in all aspects of our work. We recall with great affection and gratitude the manner in which George schooled us in both research and leadership.

The world was truly enriched by George Trilling's presence, an enrichment that lives on through his vivid legacy.

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