Velvet Revolution at the Synchrotron

Biology, Physics, and Change in Science

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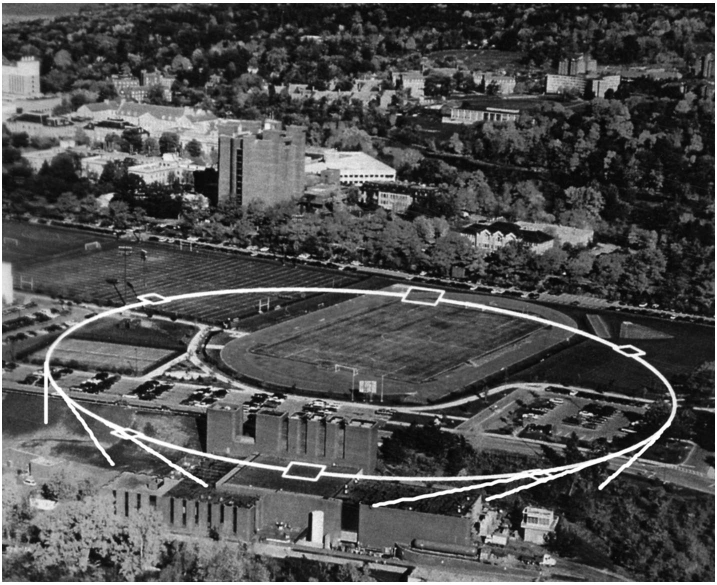
1 Birth of a Hybrid Laboratory

It is 1993. In the crystal cold hours before dawn, a campus sleeps as yet another winter night gradually unfolds into morning. Below the frozen soccer fields, however, under a thin layer of grass, 50 feet of dirt, and 2 feet of concrete, the buzz of activity is lively and constant. Electric fields oscillate. Magnetic fields hold strong and steady. Electrons orbit at nearly the speed of light inside a roughly circular evacuated metal pipe while their counterparts, positrons, pass them by, traveling just as fast in the opposite direction. X-rays emitted by the accelerated subatomic particles emanate at a tangent to the circle, traveling straight down pipes connected to the ring. Lights flash. Needles waver. Numbers blink on screens. The machine is on. That's what the laboratory members call it: "the machine."

In this book—a study of a present-day hybrid physics and biology synchrotron laboratory—I examine the relationship between technical knowledge claims and organizational modes of authority and control. Through an analysis of three episodes—one involving contestations over instrumentation development, one involving laboratory operations, and one involving methods of experimentation—I explore how laboratory members engage in "epistemic politics" whereby technical knowledge claims are



Schematic of the particle accelerator and tangential x-ray beamlines underneath Cornell's soccer fields. The laboratory building is at the bottom of the picture. (Cornell 2000)

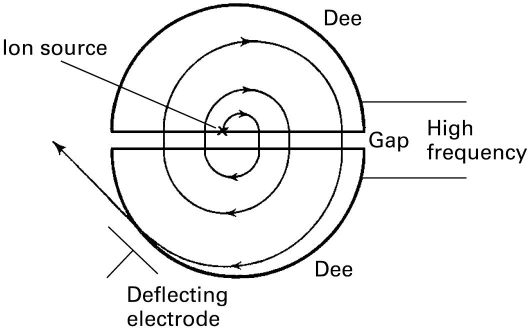
implicated in modes of authority, access, and control. Further, I assert that the epistemic-political order at the lab changed in conjunction with the rise of protein crystallography in synchrotron science at the end of the twentieth century. Finally, I question what this change means for the epistemic status of scientific facts used in, and emanating from, the laboratory.

Around the machine, all underground, are control rooms, cavernous halls, offices, hallways, and lounges. In this labyrinth, scientists, technicians, machinists, operators, and administrative personnel work to produce and account for the output of the machine. Among these various *types of staff members working in, around, and on the machine, there is an important distinction: one group—the particle group—is interested in the smaller particles produced by electron-positron "interactions" as monitored by their detector. The other group—the x-ray lab—is interested in how x-rays that emanate from the machine interact with various materials.*

I want to bring out "what the lab is" as it unfolded for me and as it changed. I want to show how different conceptions of technical practice and technical practitioners at the lab were put to use at different times by various lab members in the course of their work. Considering how understandings of who can produce knowledge and how they can do so changed in the course of the technical life of the lab is a means of exploring the relationship between the contingency of scientific practice and the output of that practice.

As dawn breaks, the machine's operator arranges for the positrons and electrons to collide, all the while monitoring vacuums, temperatures, beam intensities, and beam positions. With regard to the particle collisions, records of the results from this night will be added to those of previous and future nights, months, and years in the hope of producing indications of the actions of a particular particle of subatomic matter, the B-meson. At the same time, the archived signals from various reflective, refractive, and diffractive interactions between the emanating x-rays and various material, chemical, and biological samples are recorded in the hope of producing descriptions of the structural arrangement of atoms within those samples.

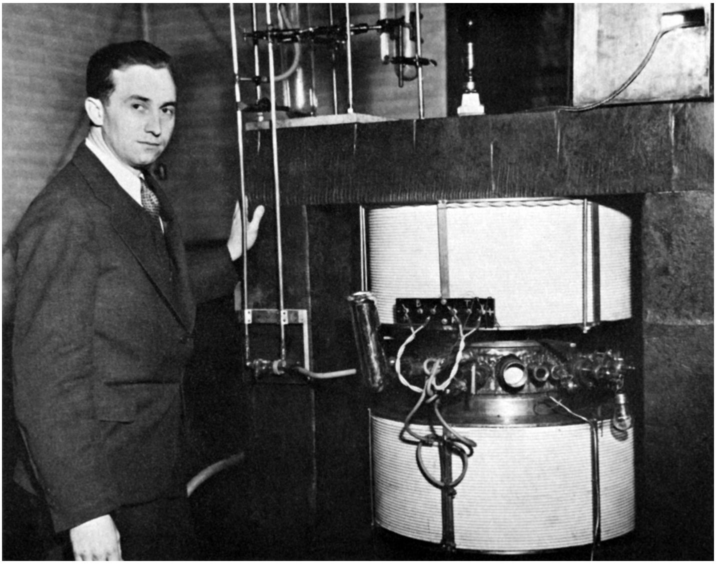
The laboratory that is the focus of this book began at Cornell University in 1934, or in 1946, or in 1976, or even at some other



Schematic diagram of a cyclotron. (Bluh and Elder 1955)

time or place, for that is part of the question: Just what *is* the laboratory? Certainly the first cyclotron built in the United States after the one in Ernest Lawrence's laboratory at the University of California at Berkeley was built at Cornell University in 1934 (Heilbron and Seidel 1989).

A cyclotron works by accelerating electrons in an ever-widening spiral inside flat, semicircular copper "electrodes" and then ejecting those electrons at the outer edge of one of the electrodes. By this means, a cyclotron can accelerate electrons to speeds within a few percentage points of the speed of light. Invented during the race to be the first to "split" an atom's nucleus, cyclotrons were important during the 1930s, when subatomic interactions were first explored (Cathcart 2004). In the 1930s, cyclotrons were also used to induce radioactivity in elemental samples, which made them useful in medicine and in biological research. This connection was important for the funding of early cyclotrons, and it enabled continued work in accelerator physics in the United States during the Great Depression, when money for physics was scarce. In the early years, in order to make sufficient quantities of



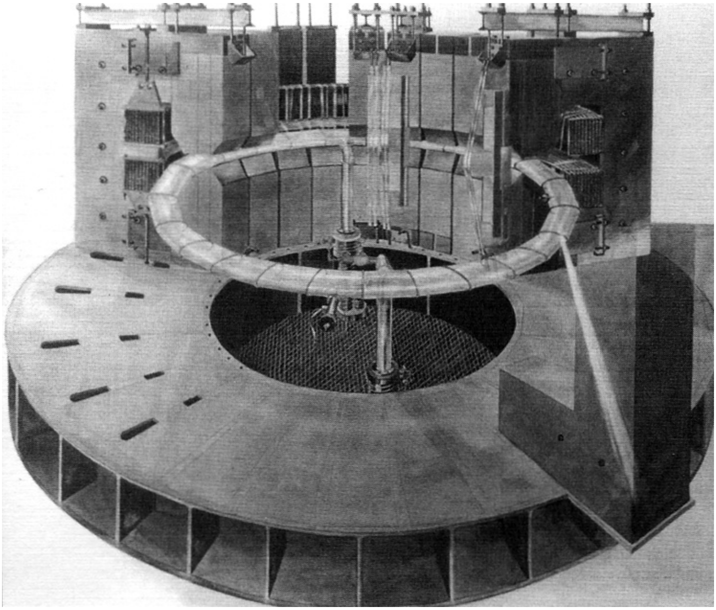
Milton Stanley Livingston with the 1929 cyclotron in Berkeley (Heilbron and Seidel 1989)

isotopes to meet the medical demand, scheduled crews of physicists worked around the clock at Lawrence's lab, producing prespecified radioactive sources. While this work came to be seen as "downright drudgery," and Lawrence himself became concerned about the bureaucratic transformation engendered by the emphasis on biomedical isotope production, biological work remained a mainstay of Lawrence's laboratory through the years leading up to World War II (ibid.: 306). Lawrence even appeared on radio shows with radioactive salt produced by his machine to demonstrate, by holding the salt on one side of his body and a Geiger counter on the other, the power of the radiation (Heilbron and Seidel 1989: 191). Nearly all the cyclotrons built subsequently during this time in the United States were dedicated to biomedical work, which was still "paramount in acquiring financial support for their construction" (ibid.: 301). By 1940, this meant 20 out of 23 facilities. The Cornell machine initiated this first wave of expansion, although it was one of the few machines built for physics rather than biology. In the years leading up to the war, important contributions to nuclear physics and improvements in the design of cyclotrons were seen to arise from work done with the Cornell machine (ibid.: 301).

After the dramatic success of physics and physicists in the war, particle physics became a national priority. At many universities, alumni of the Manhattan Project and of the Los Alamos Laboratory were granted resources with which to start or to greatly expand programs in high-energy physics. These programs were built on the promise of a new and more powerful generation of circular accelerators: synchrotrons. Rather than accelerate electrons inside a copper plate and then eject them, a synchrotron accelerates electrons in a vacuum inside a circular metal pipe. This makes it possible to accelerate the electrons to about 99 percent of the speed of light. The builders of the 1934 Cornell cyclotron, who had since been involved in the Manhattan Project and the Los Alamos Laboratory, approached Cornell University's president, Edmund Ezra Day, and informed him that they all had offers to go elsewhere to conduct nuclear research. They made it clear that they preferred to stay, but that Cornell would have to provide "adequate opportunities" for "constructive work," including the construction of a synchrotron. In response to this request, Cornell's board of trustees promptly allocated $1.2 million for "specific support of the nuclear studies project" (Schweber 1992: 177). "No decision of the Board of Trustees during my term of office," President Day told the physicists, "has been of greater importance to this institution and to the prospects of scientific research in this country.” (ibid.: 178) With additional funds from the Office of Naval Research, the building of an accelerator at Cornell was under way.

In a repeating pattern, the machine operator injects first electrons and then positrons into the storage ring. After each injection, an “experimental run” officially begins. Once the run begins, the operator will continue to make adjustments so that these particles will circulate efficiently in the machine and will collide at just the right place. How much adjustment is appropriate—and even what such adjustment actually is—is a topic of contestation at the lab. For now, over the lab-wide intercom, the machine operator announces to both the x-ray group and the particle group that the run has started. Each experimental run, during which the particle physics group and the x-ray lab conduct their experiments simultaneously, lasts an hour. At the end of the hour, the machine operator announces the end of the run, “dumps” the remaining particles from the ring, and begins a new run.

The Cornell particle physicists began their program of synchrotron building after World War II with a 300-MeV (mega-electron-volt) machine. An electron-volt is the amount of energy gained by a single electron when it is accelerated through an electrostatic potential of one volt. How many electron-volts a synchrotron is capable of producing is directly related to how fast the electrons can travel in that synchrotron. The members of the solid-state physics group at Cornell were aware that a new synchrotron was being built in their midst and that synchrotrons could produce very powerful x-rays. In 1946, when such “synchrotron x-rays” were first noticed by a technician working on a synchrotron at



Schematic of the Cornell 300-MeV synchrotron. The first-ever synchrotron beamline was, on occasion, connected to this device. A swath of x-rays is shown as emanating from the device. (Patterson 2002)

General Electric's laboratory in Schenectady, a member of the Cornell solid-state group immediately visited the GE lab to witness the phenomenon (Hartman 1988: 4). Upon his return to Cornell, members of the solid-state group began to formulate (with help from members of the particle physics group) plans for how they might use the synchrotron on their campus for research. One of the solid-state researchers described his first cautious approach to the particle physics group about the use of x-rays from the synchrotron as follows:

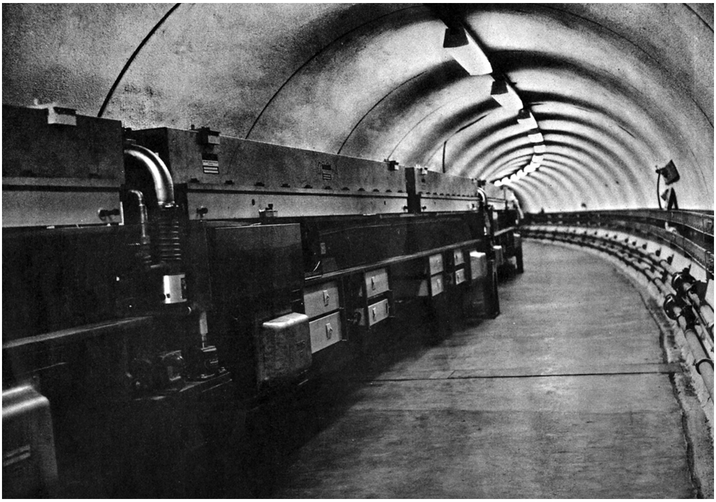
> I went one day down [the hall] to see the x-ray physicist . . . about the possibility of using [x-rays] of a low voltage, high current x-ray tube. He

> was not very encouraging but suggested instead that the synchrotron be used. . . . As a source for my research, the prospect was not the most appealing; the high energy people had their own program, it was a complicated source, and to have two differently oriented laboratories in the same space seemed pretty unrealistic. But the prospect of doing something in my energy range, yet of real interest to the high energy people seemed exciting and useful. (Hartman 1988: 4)

With a colleague, this researcher then approached the head of the atomic physics group about getting some "machine time." The director, it turned out, was "more than agreeable," and they "made plans" (ibid.: 5). Thus, in 1946, the first synchrotron radiation beam time was arranged. The solid-state physicists described the first time they were allowed to use this "machine" as "a satisfying night for us, if not for the high energy crew running the machine, to whom we were indebted" (ibid.: 7). So began a unique collaboration in the world of physics. Describing the initial relationship between the two groups, one of the solid-state physicists involved said: "It was clear that the radiation was there, it was intense, and could be useful. But it was also clear that we were all going to be pirates and that the high energy [particle physics] people were not building their machine(s) with us in mind." (ibid.: 7) For about 10 years, while the 300-MeV machine continued to contribute to particle physics research, the "pirates" conducted important early characterizations of x-ray synchrotron radiation when they could access the machine. Over the next 50 years, this relationship changed. The "pirates" permanently boarded the vessel. Moreover, these pirates had other pirates in their midst.

During laboratory running periods, another pattern of operation repeats. On four or five days of every week the lab conducts experimental runs. Members of the lab's staff and members of the experimental *groups "pull shifts" around the clock. On the other two days, the particle group conducts "machine studies"—experimental tests that are used to gather new information about the capabilities of the machine, the detector, and the x-ray lab. "Machine studies" time is also used to test new components of the machine, the detector, and the x-ray lab. The relationship between machine studies and experimental running is contested at different times in different ways at the lab. Nevertheless, between these two functions (experimental runs and machine studies) the laboratory is staffed, open, and operating 24 hours a day, 7 days a week, 52 weeks a year, although this pattern is broken when the laboratory interrupts the running periods, sometimes for months at a time, to upgrade the facility.*

In the mid 1960s, Cornell's particle physics group built a second and larger synchrotron. When it was commissioned, this synchrotron boasted the highest electron energy in the world: 10 GeV. For more than 10 years it supported a successful experimental program in particle physics, including the exploration of a newly discovered subatomic particle: the B-meson. This machine ran through 1975, when the particle physics group submitted a proposal to the National Science Foundation to "modify" its synchrotron facility. This proposal called for the construction of an electron-positron colliding-beam storage ring, for which the existing synchrotron would serve as the injection device. In this storage ring, electrons and positrons would be accelerated around at the same time in the same pipe but in opposite directions. (A positron reacts as a positively charged electron to electric and magnetic fields.) The particles would weave in and out of one another in bunches, and would be made to collide, head on, at a particular point in the ring, thus greatly increasing the energy of collision. Before this proposal, all colliding-beam machines in the



The tunnel in the 1970s before the storage ring was built. This photo hung in a hallway of the laboratory. The device in the tunnel is the 10-GeV synchrotron

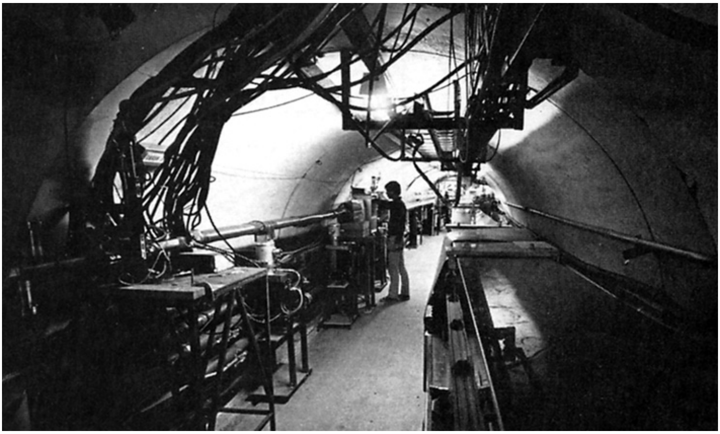
United States operated at the same energy. This proposed storage ring would operate at a different and somewhat variable energy and thus would “substantially increase the flexibility of the national program” (CESR 1977: 24). The phenomena to be studied included possible new hadronic and leptonic degrees of freedom, the spectroscopy of hadronic resonances, hadronic dynamics as revealed by multiple production, photon-photon collisions, the properties of quantum electrodynamics at very short distances, and the relation between weak and electromagnetic processes (ibid.: 9–22).

The proposal was initially reviewed by the National Science Foundation’s High Energy Physics Advisory Panel’s sub-panel on New Facilities. Although the sub-panel commented favorably “with regard to the technical aspects and physics capabilities,” the facility was recommended for construction “only under conditions of a high level of federal funding” (ibid.: 1). Such a high level of federal funding, however, did not emerge immediately. Despite that initial setback, the Cornell physicists, confident in their proposal and sure of their direction, proposed in December of 1975 that they use $450,000 of their already allocated operating budget to begin preliminary work on designs that could be incorporated into the new facility. This request was approved. A similar agreement was reached to use another $1.2 million from the operating budget in 1976 for colliding-beam research and development (ibid.: 2). In 1977, the original proposal was again submitted, requesting $20 million over three years for the design and commissioning of an electron-positron storage-ring facility.

As the storage-ring proposal was again being considered by the National Science Foundation, the solid-state researchers at Cornell began building support in their field for the proposed ring, but for different purposes. By that time, the importance of synchrotron radiation science was internationally recognized. The U.S. Department of Energy was arranging for the construction of two synchrotron rings that would be dedicated radiation facilities. In this general climate, and with the specific proposal for a ring on their campus, the solid-state group at Cornell arranged for a “Workshop on the Application of Synchrotron Radiation to X-ray Diffraction Problems in Materials Science” to be held in the summer of 1977 (Batterman 1977). This workshop raised the solid-state group’s institutional visibility and importance further and provided a unified argument explaining why sharing the storage-ring resource and collaboration with the particle group would lead to good science by advancing a variety of research fields. In diffraction physics, alloys and ceramics could be studied.

Surface studies and crystallography of very small crystals could be pursued. Studies of biophysical materials (e.g., muscle and membrane) showed promise. The report of the meeting asserts that synchrotron radiation had “great value in the characterization of materials for industrial processes, particularly in the semiconductor and electronic device industries,” and that x-ray techniques to determine “nearest neighbor environments” of electrons in an atom were a valuable resource in “many areas of chemical, solid state, biological, and materials sciences.” The report also discussed the use of synchrotron x-rays for “macromolecular crystallography,” the determination of the structures of viruses and proteins (ibid.: 5–11).

In September of 1977, the organizers of the workshop submitted to the National Science Foundation a request for $1.4 million over three years. The proposal was to incorporate x-ray beamlines into the new storage-ring facility that was being proposed by the particle group at Cornell (CHESS 1977). This proposal was submitted separately from the particle group’s proposal, but it referred to ongoing communication between the groups to show that this request had the support of the particle group. The scientific argument in the proposal followed along the lines of the conclusions of the workshop. In addition to this scientific argument, the proposal outlined the history of cooperation between the high-energy physics group and the x-ray physics group at Cornell. It also noted the timing, the cost effectiveness, and the scientific uniqueness of the proposed synchrotron radiation facility. Specifically, the proposal relied on the following lines of reasoning: Fist, the new facility could provide synchrotron x-ray radiation, which was currently available only at one facility in the United States—a facility that was far from the site of the proposed new lab (ibid.: 5). Second, even though a much larger ring dedicated



Tunnel with storage ring and synchrotron, circa 1983. (Batterman 1986)

to synchrotron x-radiation was under construction not far away, the proposed lab would come on line more than a year ahead of the dedicated facility, thus providing interim "relief for the ever increasing demands of synchrotron radiation" (ibid.: 7). Third, since the x-ray lab would be parasitic to an already planned ring, the x-ray facility would be extremely cost effective ($460,000 per year) (ibid.: 7). Finally, because of the nature of the storage ring, the proposed radiation laboratory would have available certain high-energy x-rays at intensities that even the national facility would not be able to provide. This would allow the laboratory to "attack unexplored problems of a fundamental nature" (ibid.: 5).

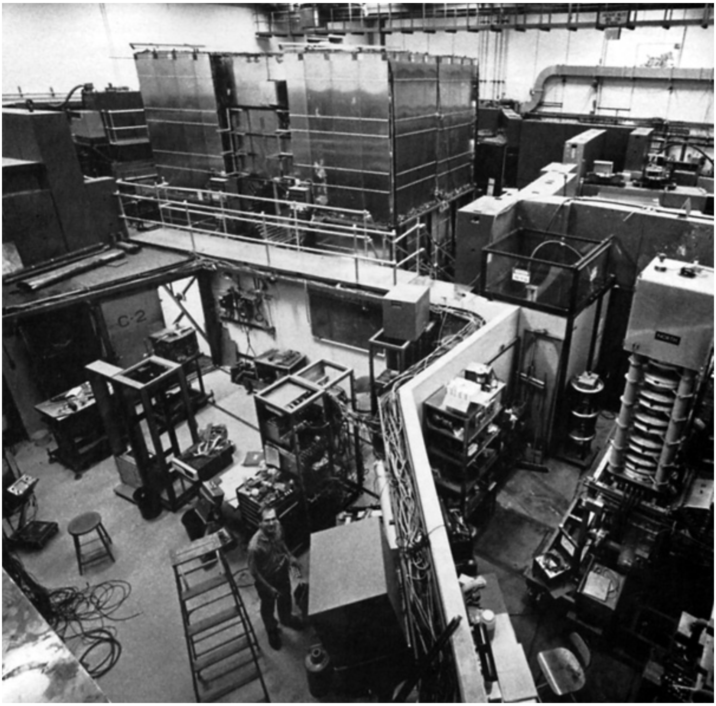
Even though the original colliding-beam ring proposals by the particle physics group in 1975 and 1976 did not mention the possibility of supporting a synchrotron radiation facility, in 1977 the particle physics group submitted an updated design report, noting that "the utility of synchrotron radiation in the physical and biological sciences is well documented" (CESR DR 1977: 11.1) and

Inside the tunnel, circa 1983. (Cornell 2000)

that "while many (synchrotron x-ray) needs can be met by dedicated facilities [the proposed storage ring] can make an important contribution as an alternative source in the hard X-ray, X-ray, and, to a lesser extent in the VUV region" (ibid.: 12.1) In the end, the balance of opportunity cost, scientific possibilities, location, and the history and spirit of cooperation between these two groups of physics researchers proved compelling. In 1978 the proposals for the Cornell Electron Storage Ring (CESR) and the associated synchrotron x-ray facility, called the Cornell High Energy Synchrotron Source (CHESS), were both approved by the National Science Foundation. With government money and with infrastructure support from the university, a new kind of laboratory—a hybrid particle physics-synchrotron x-ray laboratory—was born.

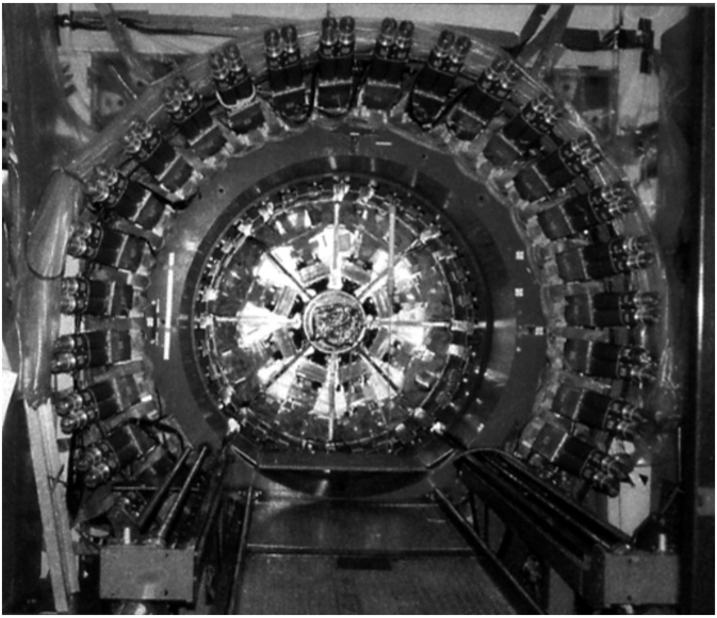
A section of the tunnel in 2001, showing the synchrotron as it bypassed the particle physics detector. (P. Doing)

As each experimental run proceeds, the particle group and the x-ray group are engaged in different kinds of actions, with different rhythms and different concerns. In the particle group's "counting room," above the machine, people (mostly graduate students) watch over a bank of computer monitors as raw data from the electron-positron collisions appear on screens. A scientific result is not immediately discernible, but one emerges after signals collected over several months are stored and analyzed. The counting room makes sure that the collection equipment is working properly, that there are sufficiently strong signals, and that the data are being archived. A few minutes of fluctuation or down time do not matter as long as the machine and the data-collection equipment are working generally. On the floor below, however, just outside the ring area, experimenters and equipment operators watch the intensity and the position of the particle beams closely, since small fluctuations in the



Looking down onto part of the experimental floor. The particle group's detector is inside the large assembly visible in the background. The C-2 x-ray experimental station is visible to the left. (Batterman 1986)

trajectory of the beams, and x-rays that emanate from them, have large effects on experiments that are lined up to detect "scattered" x-rays at extremely precise angles. Most experimenters at the x-ray lab have arranged "beam time" for one or two weeks and probably will not be able to return for a year or more. For many of them, these "run weeks" will determine the topic of a dissertation or a year's publication output. Tensions can run high. The pressure can be felt on the floor. To these groups, delays of even minutes may matter.



Looking into the particle physics group's detector known as CLEO. (Cornell 2000)

When the new laboratory was launched, the relationship between the x-ray group and the particle physics group with regard to the synchrotron was explicitly stipulated by the particle physics group in memos to the x-ray physicists and to the National Science Foundation. The particle physics group's updated 1977 technical report to the NSF asserts that, although "every attempt will be made to maintain a compatible and productive synchrotron radiation facility," the particle physics group will not lose sight of its mission. "As the storage ring develops," the report states, "high energy physics goals must be preserved" (CESR DR 1977: 12-3). The relationship is further clarified in a memo from the director of the synchrotron lab to the leaders of the x-ray radiation lab dated October 3, 1977. This memo was also attached to the technical report sent to the NSF. After conveying his “enthusiastic support” for the x-ray facility and noting that “the effective use of the unique synchrotron radiation of the storage ring for research purposes is an exciting objective,” the particle group’s director states “we should assist you in establishing this program in every way that is consistent with our available resources and with the priority of our program in high energy particle physics” and adds these comments:

> It is recognized that the primary mission of the CESR laboratory is the high-energy particle physics program. The activities of the CHESS laboratory and the services which the Laboratory of Nuclear Studies will supply must be consistent with this priority. As a consequence, it is expected that CHESS will operate predominantly in a strictly parasitic mode. However, we realize that under special circumstances, it may be extraordinarily useful for CHESS to be able to control the characteristics of the beam and the mode of operation of the storage ring. As a consequence, we agree to make provision for a certain amount of time when the storage ring will operate in the mode specified by the CHESS Laboratory directorate. (CESR DR 1977, appendix A)

For 3 percent of the time, the x-ray facility would control the ring. For the other 97 percent of the time, x-ray operation would be “strictly parasitic.” From pirates to parasites, the solid-state physicists had come a long way. Even if constrained, they now had official status and access to a unique and powerful x-ray source. With this pact in hand, both groups got down to the business of vigorously pursuing the new scientific opportunities that lay before them.

For several decades, the laboratory thrived. In a scientific landscape in which the colossal Superconducting Supercollider had been approved and was under construction and dozens of dedicated x-ray synchrotron laboratories were coming on line around the world, the particle group at the Cornell laboratory contributed importantly to B-meson physics, and the solid-state group a wide variety of research in materials science and biology. The laboratory's staff grew to several hundred, housed in offices located above the synchrotron and the storage-ring tunnel, the x-ray experimental floor, and the adjacent machine shop and fabrication space.

Beginning in the 1990s, however, an important change occurred at the lab and in the field. Protein crystallography, once only a small part of the x-ray research (which was itself secondary to the particle physics work at the lab), gained more and more prominence at the lab and in science at large. As anticipation grew that the Human Genome Project would result in full control over disease and health, and as developments in the combination of molecular biology and information technology advanced, funding in science flowed toward research with biological applications. Meanwhile, public interest in particle physics waned, and funding for such research was scaled back. The Superconducting Supercollider project was halted in the midst of construction (Kevles 1995, 1997). As scientific prestige in the form of publications, funding, and professorships accrued to research in biology in general and in the structure of viruses and proteins in particular, including the awarding of the Nobel Prize in chemistry in 2003 for protein crystallography work done in part at the Cornell lab, practice at the laboratory changed. Who could properly produce technical and scientific knowledge, and how, was different at the end of my study than it had been at the beginning. In this book, I explore these changes at the lab and wrestle with their implications.

The wind gusted through the glass door as I entered the laboratory building from the parking lot across from the soccer fields. The lobby area was nondescript—just a small coffee table and a chair of metal and fabric beside an elevator—except for one item. Leaning forward from the side wall of the high-ceilinged foyer was a life-size praying "maiden" carved from wood and taken off of the prow of a sailing ship. With her hands folded in front of her, she watched over those who passed in and out of the lab, silently guiding their passage and the journey of the machine. As I was envisioning her earlier life at the front of her previous vessel, pressing through the waves of past travels, the elevator's bell chimed and its doors slid open in front of me. I stepped forward and turned around as the doors glided shut. My stomach lurched as the elevator car bumped into motion.