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A BRIDGE TOO FAR
The demise of the Superconducting Super Collider

Michael Riordan

The largest basic scientific project ever attempted, the supercollider proved to be beyond the management capacity of the US high-energy physics community. A smaller proton collider would have been substantially more achievable.

When the US Congress terminated the Superconducting Super Collider (SSC) in October 1993 after about $2 billion had been spent on the project, it ended more than four decades of American leadership in high-energy physics. To be sure, US hegemony in the discipline had been deteriorating for more than a decade, but the SSC cancellation was the ultimate blow that put Europe unquestionably in the driver's seat and opened the door to the discovery of the Higgs boson at CERN (see PHYSICS TODAY, September 2012, page 12). The causes and consequences of the SSC's collapse, a watershed event in the history of science, have been discussed and debated ever since it happened.

At least a dozen good reasons have been suggested for the demise of the SSC.[1–4] Primary among them are the project's continuing cost overruns, its lack of significant foreign contributions, and the end of the Cold War. But recent research and documents that have come to light have led me to an important new conclusion: The project was just too large and too expensive to have been pursued primarily by a single nation, however wealthy and powerful. Wolfgang "Pief" Panofsky, founding director of SLAC, voiced that possibility during a private conversation in the months after the project's demise; he suggested that perhaps the SSC project was "a bridge too far" for US high-energy physics. That phrase became lodged firmly in my mind throughout the many years I was researching its history.

Some physicists will counter that the SSC was in fact being pursued as an international project, with the US taking the lead in anticipation that other nations would follow; it had done so on large physics projects in the past and was doing so with the much costlier International Space Station.[5] But that argument ignores the inconvenient truth that the gargantuan project was

VIEW ALONG THE SUPERCONDUCTING SUPER COLLIDER main-ring tunnel, in early 1993. (Courtesy of Fermilab Archives.)

ROSE GARDEN CEREMONY. Secretary of energy John Herrington (at lectern) and President Ronald Reagan (next to him) stress the importance of building the Superconducting Super Collider to an audience of top high school students, Nobel laureates, and others on 30 March 1988. Joining them, from left, are Samuel Ting (MIT), Steven Weinberg (University of Texas at Austin), and Burton Richter (then director of SLAC). (Courtesy of the Ronald Reagan Presidential Library.)

launched by the Reagan administration as a deliberate attempt to reestablish US leadership in a scientific discipline the nation had long dominated. If other nations were to become involved, they would have had to do so as junior partners in a multibillion-dollar enterprise led by US physicists.

That fateful decision, made by the leader of the world's most powerful government, established the founding rhetoric for the SSC project, which proved difficult to abandon when it came time to enlist foreign partners.[6]

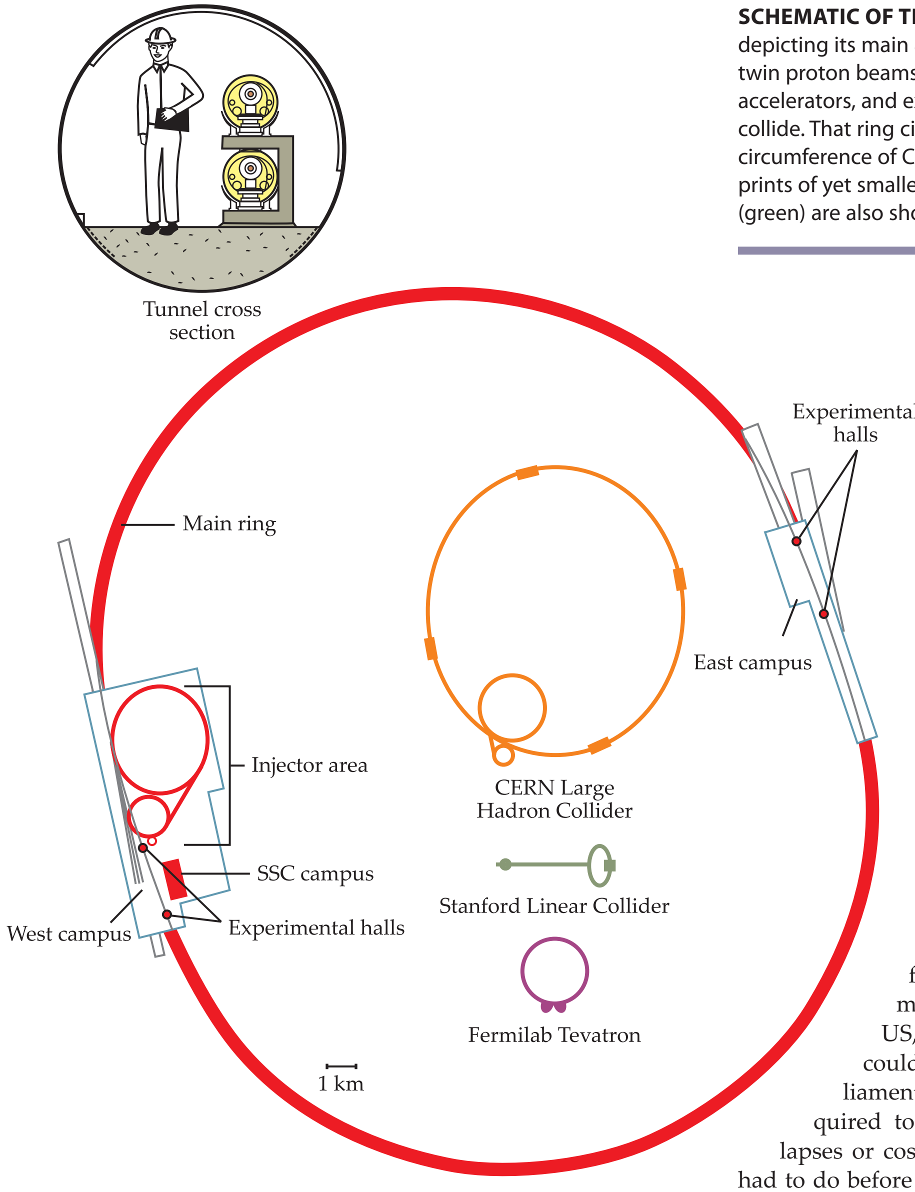
The SSC and the LHC

In contrast, CERN followed a genuinely international approach in the design and construction of its successful Large Hadron Collider (LHC), albeit at a much more leisurely pace than had been the case for the SSC. Serious design efforts begun during the late 1980s and early 1990s ramped up after the SSC's termination. Although the LHC project also experienced trying growth problems and cost overruns—its cost increased from an estimated 2.8 billion Swiss francs ($2.3 billion at the time) in 1996 to more than 4.3 billion Swiss francs in 2009—it managed to survive and become the machine that allowed the Higgs-boson discovery using only about half of its originally designed 14 TeV energy.[7] (The SSC, by comparison, was designed for 40 TeV collision energy.) When labor costs and in-kind contributions from participating nations are included, the total LHC price tag approached $10 billion, a figure often given in the press. Having faced problems similar to, though not as severe as, what the SSC project experienced, the LHC's completion raises an obvious question: Why did CERN and its partner nations succeed where the US had failed?

From the SSC's early days, many scientists thought it should have been sited at or near Fermilab to take advantage of the existing infrastructure, both physical and human. University of Chicago physicist and Nobel laureate James Cronin explicitly stated that opinion in a letter he circulated to his fellow high-energy physicists in August 1988. CERN has followed that approach for decades, building one machine after another as extensions of its existing facilities and reusing parts of the older machines in new projects, thereby reducing costs. Perhaps as important, CERN had also gathered and developed some of the world's most experienced accelerator physicists and engineers, who work together well. During the late 1980s, Fermilab had equally adept machine builders—plus substantial physical infrastructure—who could have turned to other productive endeavors when the inevitable funding shortfalls occurred during the annual congressional appropriations process.

Troublesome clashes occurred at the SSC between the high-energy physicists and engineers who had been recruited largely from the shrinking US military–industrial complex as the Cold War wound down during the late 1980s and early 1990s.[8] For example, the methods by which SSC general manager Edward Siskin and magnet division director Thomas Bush managed large projects and developed sophisticated components differed greatly from those customarily employed by high-energy physicists. A particular bone of contention was the project's initial lack of a cost-and-schedule control system, which by then had become mandatory practice for managing large military-construction and development projects overseen by the Department of Defense. Such clashes would probably not have erupted in the already well-integrated Fermilab high-energy physicist culture, nor would the disagreements have been as severe.

Those pro-Fermilab arguments, however, ignore the grim realities of the American political process. A lucrative new project that was to cost more than $5 billion and promised more than 2000 high-tech jobs could not be sole-sourced to an existing US laboratory, no matter how powerful its state congressional delegation. As politically astute leaders of the Department of Energy recognized, the SSC project had to be offered up to all states able to provide a suitable site, with the decision based (at least publicly) on objective, rational criteria. Given the political climate of the mid 1980s, a smaller project costing less than $1 billion and billed as an upgrade of existing facilities might have been sole-sourced to Fermilab, but not one as



SCHEMATIC OF THE SUPERCONDUCTING SUPER COLLIDER, depicting its main 87 km ring—designed to circulate and collide twin proton beams, each at energies up to 20 TeV—the injector accelerators, and experimental halls, where the protons were to collide. That ring circumference is more than three times the 27 km circumference of CERN's Large Hadron Collider (orange). The footprints of yet smaller particle colliders at Fermilab (purple) and SLAC (green) are also shown for comparison. (Adapted from ref. 2.)

prominent and costly as the SSC. It *had* to be placed on the US auction block, and Texas made the best bid according to the official DOE criteria.

Unlike the SSC, the LHC project benefited from the project management skills of a single physicist, Lyndon Evans, who came to the task with decades of experience on proton colliders. Despite the facility's major problems and cost overruns, Evans enjoyed the strong support of the CERN management and a deeply experienced cadre of physicists and engineers. On the LHC project, engineers reported ultimately to physicists, who as the eventual users of the machine were best able to make the required tradeoffs when events did not transpire as originally planned. The project encountered daunting difficulties and major delays, including the September 2008 quench of dozens of superconducting magnets. But the core management team led by Evans worked through those problems, shared a common technological culture, and understood and supported the project's principal scientific goals.

Similar observations cannot be made regarding the military–industrial engineers who came to dominate the SSC lab's collider construction. Until 1992 a succession of acting or ineffectual project managers could not come to grips with the demands of such a complex, enormous project that involved making countless decisions weekly. Secretary of energy James D. Watkins deliberately had Siskin inserted into the SSC management structure in late 1990 in an effort to wrest control of the project from the high-energy physicists. After SLAC physicist John Rees stepped in as the SSC project manager in 1992, he and Siskin began working together effectively and finally got a computerized cost-and-schedule control system up and running—and thus the project under better control. But it proved to be too late, as the SSC had already gained a hard-to-shake reputation in Congress as being mismanaged and out of control.

CERN also enjoys an enviable internal structure, overseen by its governing council, that largely insulates its leaders and scientists from the inevitable political infighting and machinations of member nations. Unlike in the US, the director general or project manager could not be subpoenaed to appear before a parliamentary investigations subcommittee or be required to testify under oath about its management lapses or cost overruns—as SSC director Roy Schwitters had to do before Congress. Nor did the LHC project face annual congressional appropriations battles and threats of termination, as did major US projects like the SSC and the space station. Serious problems that arose with the LHC—for example, a large cost overrun in 2001—were addressed in the council, which represents the relevant ministries of its member nations and generally operates by consensus, especially on major laboratory initiatives. That supple governing structure helps keep control of a project within the hands of the scientists involved and hinders government officials from intervening directly.

Because the council must also address the wider interests of individual European ministries, CERN leaders have to be sensitive to the pressures that the annual budget, new projects, and cost overruns can exert on other worthy science. In that manner, European scientists in other disciplines have a valuable voice in CERN governing circles. The LHC project consequently had to be tailored to address such concerns before the council would grant it final approval. In the US, the only mechanism available was for disgruntled scientists to complain openly, which Philip Anderson of Princeton University, Theodore Geballe of Stanford University, Rustum Roy of the Pennsylvania State University, and others did in prominent guest editorials or in congressional hearings when SSC costs got out of hand between 1989 and 1991. The resulting polarization of the US physics community helped undermine what had been fairly broad support for the SSC project in the House of Representatives, which in 1989 had voted 331–92 to proceed with construction.

Because of financial pressures, CERN had to effectively internationalize the LHC project—obtaining monetary and material commitments from such nonmember nations as Canada, China, India, Japan, Russia and the US—before the council would give approval to go ahead with it. When that approval finally came in 1996, the LHC was a truly international scientific project with firm financial backing from more than 20 nations. Those contributions enabled Evans and his colleagues to proceed with the design of a collider able to reach the full 14 TeV collision energy as originally planned.

Scale matters

In hindsight, the LHC was (somewhat fortuitously) more appropriately sized to its primary scientific goal: the discovery of the Higgs boson. The possibility that this elusive quarry could turn up at a mass as low as 125 GeV was not widely appreciated until the late 1980s, when theories involving supersymmetry began to suggest the possibility of such a light Higgs boson emerging from collisions. But by then the SSC die had been cast in favor of a gargantuan 40 TeV collider, 87 km in circumference, that would be able to uncover the roots of spontaneous symmetry breaking even if the long-anticipated phenomenon required the protons' constituent quarks and gluons to collide with energies[9] as high as 2 TeV. When it became apparent in late 1989 that roughly $2 billion more would be needed to reduce design risks that could make it difficult for the SSC to attain its intended collision rate, Panofsky argued that the project should be down-scoped to 35 TeV to save hundreds of millions of dollars. But nearly everyone else countered that the full 40 TeV was required to make sure users could discover the Higgs boson—or whatever else was responsible for spontaneous symmetry breaking and elementary-particle masses.

A US High-Energy Physics Advisory Panel (HEPAP) subpanel, chaired by SLAC deputy director Sidney Drell, unanimously endorsed that fateful decision in 1990. The US high-energy physics community had thus committed itself to an enormous project that became increasingly difficult to sustain politically amid the worsening fiscal climate of the early 1990s. With the end of the Cold War and subsequent absence of a hoped-for peace dividend during a stubborn recession, the US entered a period of fiscal austerity not unlike what is now occurring in many developed Western nations. In that constrained environment, a poorly understood basic-science project experiencing large, continuing cost overruns and lacking major foreign contributions presented an easy political target for congressional budget cutters.

A 20 TeV proton collider—or perhaps just a billion-dollar extension of existing facilities such as the 4–5 TeV Dedicated Collider proposed by Fermilab in 1983—would likely have survived the budget axe and discovered the light Higgs boson long ago.[10] Indeed, another option on the table during the 1983 meetings of a HEPAP subpanel chaired by Stanford physicist Stanley Wojcicki was for Brookhaven National Laboratory to continue construction of its Isabelle collider while Fermilab began the design work on that intermediate-energy proton–antiproton collider, whose costs were then projected at about $600 million.

That more conservative, gradual approach would have maintained the high-energy physics research productivity of the DOE laboratories for at least another decade. And such smaller projects would certainly have been more defensible during the economic contractions of the early 1990s, for they aligned better with the high-energy physics community's diminishing political influence in Washington. Their construction would also have been far easier for physicists to manage and control by themselves without having to involve military–industrial engineers.

SLAC DEPUTY DIRECTOR SIDNEY DRELL (left) and emeritus director Wolfgang Panofsky (right) talk in late 1992 with Louisiana senator J. Bennett Johnston, the Superconducting Super Collider's leading supporter in Congress. (Courtesy of Ed Souza, Stanford News Service.)

The Wojcicki subpanel had originally recommended that the US design a 20–40 TeV collider, but that was before European physicists led by CERN decided in 1984 to focus their long-range plans on a 14 TeV proton collider that they could eventually achieve by adding superconducting magnets to the Large Electron–Positron Collider (LEP) then under construction. (Actually, they considered 18 TeV achievable when they made this decision.) Lowering the SSC energy as Panofsky suggested thus risked Congress raising the awkward question that had already been voiced by SSC opponents, "Why don't US physicists just join the LHC project and save US taxpayers billions of dollars?" Although justified on purely physics grounds, the 1990 decision to keep the original SSC energy clearly had a significant political dimension, too.

SUPERCONDUCTING SUPER COLLIDER DIRECTOR ROY SCHWITTERS (right) guides President George H. W. Bush (center) on a tour of the SSC magnet test laboratory on 30 July 1992. Accompanying them are, from left, presidential science adviser D. Allan Bromley, Texas congressman Joe Barton, and deputy undersecretary of energy Linda Stuntz. (Courtesy of Fermilab Archives.)

The US high-energy physics community therefore elected to "bet the company" on an extremely ambitious 40 TeV collider, so large that it ultimately had to be sited at a new laboratory in the American Southwest, as was originally envisioned in 1982. Such a choice, however, meant abandoning the three-laboratory DOE system that had worked well for nearly two decades and had fostered US leadership in high-energy physics. (That was Cronin's primary concern when he urged his fellow physicists and DOE to site the SSC at Fermilab.) But perceived European threats to US hegemony and Reagan administration encouragement tipped the balance toward making the SSC a national project and away from it becoming the truly international "world laboratory" that others had long been advocating.

Infrastructure problems

In retrospect, the SSC leadership faced two daunting tasks in establishing a new high-energy physics laboratory in Waxahachie, Texas:

- Building the physical infrastructure for a laboratory that would cost billions of US taxpayer dollars and was certain to be a highly visible, contentious project.
- Organizing the human infrastructure needed to ensure that the SSC became a world-class laboratory where scientists could do breakthrough high-energy physics research.

Addressing those tasks meant having to draw resources away from other worthy programs and projects that competed with the SSC during a period of tight annual budgets. Reagan administration officials had insisted that the project would be funded by new money, but that was only a convenient fiction. Congress, not the president, holds the federal purse strings, so the SSC always had to compete against other powerful interests—especially energy and water projects—for its annual funding. And it usually came up short, which further delayed the project and increased its costs.

Schwitters and other managers attempted to attract top-notch physicists to staff the laboratory, but after 1988 many of its original, primary advocates in the SSC Central Design Group (CDG) returned to their tenured positions in universities and national labs. For example, CDG director Maury Tigner, who returned to Cornell University, might have been the best choice for the original project manager. (Second-tier CDG managers did go to Texas, however, as did many younger, untenured physicists.) Despite the promise and likely prestige of building a world-class scientific laboratory, the Dallas–Fort Worth area was viewed as an intellectual backwater by many older, accomplished high-energy physicists. They might have come to work there on a temporary or consulting basis, as did Rees originally, but making a permanent, full-time commitment and bringing their spouses and families with them proved a difficult choice for many.

Achieving the first daunting task in a cost-effective way thus required bringing in an alien, military–industrial culture that made realizing the second task much more difficult. Teaming with EG&G and Sverdrup Corporations helped the SSC laboratory to tap the growing surplus of military–industrial engineers. It was crucial to get capable engineers working on the project quickly so that all the detailed design and construction work could occur on schedule and costs could be controlled. But the presence of military–industrial engineers at high levels in the SSC organization served as an added deterrent to established physicists who might otherwise have moved to Texas to help organize and build the laboratory.[11]

Estimates of the infrastructure costs that could have been saved by siting the SSC adjacent to Fermilab range from $495 million to $3.28 billion. The official DOE figures came in at the lower end, from $495 million to $1.03 billion, but they ignored the value of the human infrastructure then available at Fermilab. In hindsight, the costs of establishing such infrastructure anew at a green-field site were not small. In *Tunnel Visions*, my coauthors and I estimate that the total added infrastructure costs—physical plus human—of building the SSC in Texas would have been about $2 billion.[12]

Unlike historians gazing into the past, however, physicists do not enjoy the benefit of hindsight when planning a new machine. Guided in part by the dominant theoretical paradigm, they work with a cloudy crystal ball through which they can only guess at phenomena likely to occur in a new energy range, and they must plan accordingly. And few can foresee what may transpire in the economic or political realms that could jeopardize an enormous project that requires about a decade to complete and will cost billions of dollars, euros, or Swiss francs—or, relevant today, a trillion yen. That climate of uncertainty thus argues for erring on the side of fiscal conservatism and for trying to reduce expenses by building a new machine at or near an existing laboratory. Such a gradual, incremental approach has been followed successfully at CERN for six decades now, and to a lesser extent at other high-energy physics labs.

But US physicists, perhaps enticed by Reagan administration promises, elected to stray from that well-worn path in the case of the SSC. It took a giant leap of faith to imagine that they could construct an enormous new collider at a green-field site where everything had to be assembled from scratch—including the SSC management team—and defend the project before Congress in times of increasing fiscal austerity. A more modest project sited at Fermilab would likely have weathered less opposition and still be operating today.

In the multibillion-dollar realm it had entered, the US high-energy physics community had to form uneasy alliances with powerful players in Washington and across the nation. And those alliances involved uncomfortable compromises that led, directly or indirectly, to the SSC project's demise. That community of a few thousand physicists had a small and diminishing supply of what Beltway insiders recognize as "political capital." It could not by itself lay claim to more than 5 billion taxpayer dollars when many other pressing demands were being made on the federal purse. Thus for the SSC to move forward as a principally national project meant that those physicists had to give up substantial control to powerful partners with their own competing agendas. The Texans' yearning for high-tech jobs, for example, helped congressional opponents paint the SSC as a pork-barrel project in the public mind. In the process, the high-energy physics community effectively lost control of its most important project.

A personal perspective

Part of the problem driving up the SSC costs was the project's founding rhetoric: the intention to leapfrog European advances and reassert US leadership in high-energy physics. The Reagan administration in particular was promoting US competitiveness over international cooperation; treating other nations as equal partners would not have gained the administration's support. And a smaller, say 20 TeV, proton collider would not have sufficed either, for that was much too close in energy to what CERN could eventually achieve in the 27 km LEP tunnel then under construction. The SSC therefore had to shoot for 40 TeV, which was presented as a scientific necessity but was in fact mainly a political choice. That energy was more than 20 times the energy of the Fermilab Tevatron, and the SSC proved to be nearly 20 times as expensive. And along with its onerous price tag came other, unanticipated complications—managerial as well as political—that US physicists were ill-equipped to confront. As Panofsky suggested, the SSC was indeed "a bridge too far"—a phrase he probably borrowed from the title of Cornelius Ryan's 1974 book about a disastrous Allied campaign to capture the Arnhem Bridge over the Rhine River during World War II.

I became convinced of that interpretation only in April 2014, when previously suppressed documents surfaced at the William J. Clinton Presidential Library. The documents were memos to Clinton's chief of staff regarding a draft letter being circulated among top administration officials in early 1993 by new secretary of energy Hazel O'Leary. In the letter, Clinton was to request a billion-dollar SSC contribution from Japanese prime minister Kiichi Miyazawa. Such a contribution would have helped tremendously to reassure House members that major foreign support was indeed forthcoming and perhaps would have kept the project alive. But the memos, one from science adviser John Gibbons and the other from assistant to the president John Podesta and staff secretary Todd Stern, recommended against the president sending such a letter. The latter memo was particularly adamant:

> NSC [the National Security Council] agrees that we should convey to the Japanese our firm backing for the SSC, <u>but still objects strongly</u> [emphasis in the original] to sending a letter to Miyazawa. Such a letter could be seen as suggesting that we attach greater importance to Japanese participation in the SSC than we do to Japanese efforts on other fronts, such as aid to Russia.[13]

The document underscored for me what insurmountable competition the SSC faced in securing the required billions of dollars in federal and foreign funding. Despite their political influence reaching back to the years after World War II, high-energy physicists were not accustomed to playing in the major leagues of US politics. No such letter was ever sent.

In the final analysis, the Cold War model of doing Big Science projects, with the US taking the lead unilaterally and expecting other Western nations to follow in its footsteps, was no longer appropriate. By the 1980s the global scientific community had begun an epochal transition into a multipolar world in which other nations expect to be treated as equal partners in such major scientific endeavors—especially considering the large financial contributions involved. As US high-energy physicists have hopefully learned from the 1993 termination of the SSC, it should have been promoted from day one as a genuinely international world-laboratory project.

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