

The reinvention of the SLAC National Accelerator Laboratory, 1992–2012

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ABSTRACT

This article examines the most recent history of the SLAC National Accelerator Laboratory, with particular emphasis on how this laboratory shifted its research program from accelerator-based particle physics towards astroparticle physics, cosmology and multi-disciplinary photon science. Photon science became the central experimental research program through a series of changes in the organisational, scientific, and infrastructural set-up and in its science policy context. The article shows that SLAC's reinvention unfolded in a science policy context in which funding priorities drifted towards the materials sciences and the life sciences at the expense of nuclear and particle physics, which had dominated science budgets during the Cold War. SLAC took a lead position in this global development by partly dismantling and also redeploying scientific and technical capabilities from its particle physics program for these new fields, thus, providing novel experimental facilities for user communities to expand across academia and industry.

Abbreviations: ARGOS: Advanced Research and Global Observation Satellite; ATLAS: A Toroidal LHC Apparatus; BES: Basic Energy Sciences; BMBF: Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research); DESY: Deutsches Elektronensynchrotron (German Electron Synchrotron); DOE: Department of Energy; FEL: Free Electron Laser; GLAST: Gamma-ray Large Area Space Telescope; HEP: High-Energy Physics; HEPL: Hansen Experimental Physics Laboratory; ILC: International Linear Collider; KIPAC: Kavli Institute for Particle Astrophysics and Cosmology; LCLS: Linear Coherent Light Source; LINAC: Linear Collider; NLC: Next Linear Collider; PEP: Positron Electron Proton Ring Accelerator; SLAC: Stanford Linear Accelerator Center/ SLAC National Accelerator Laboratory; SLC: Stanford Linear Collider; SPEAR: Stanford Positron Electron Accelerating Ring; SPPS: Sub-Picosecond Pulsed Source; SSRL: Stanford Synchrotron Radiation Laboratory; SSRP: Stanford Synchrotron Radiation Project; TESLA: TeV-Energy Superconducting Linear Accelerator; TTF: TESLA Test Facility

KEYWORDS

SLAC; big science; photon science; particle physics; transformation; United States; organisation

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1. Introduction

The SLAC National Accelerator Laboratory (formerly Stanford Linear Accelerator Center) is a dual-mission United States national laboratory for particle physics/particle astrophysics and photon science. Founded, in 1962, as a single-mission US national laboratory for high-energy physics (HEP; synonymous with particle physics), SLAC was one of the great successes of the strong US program in fundamental physics in the Cold War era. The laboratory facilitated ground-breaking work that led to three Nobel Prizes in physics, including the 1976 prize awarded to Burton Richter and Samuel Ting for the discovery of the J/psi particle, which essentially confirmed the Standard Model of Particles and their interactions, and set off what was called the November Revolution in particle physics. SLAC is operated by Stanford University and functions both as a National Laboratory under the supervision of the Department of Energy’s (DOE’s) Office of Science, and in some ways like a school within Stanford University, with its own faculty and with the laboratory director (currently Chi-Chang Kao) also acting in the capacity of a dean. Funding for SLAC’s operations and investments in infrastructure currently comes from the DOE programs in Basic Energy Sciences (BES) (63%) and HEP (19%), and a number of other DOE and non-DOE sources (remaining 18%).¹

The original 3 km linear accelerator (linac) for particle physics research that also gave the laboratory its original name opened for use in 1966, followed by several new infrastructure projects (see Table 1) until the mid-1990s, all purpose-built for particle physics research; some of them, however, most notably Stanford Positron Electron Accelerating Ring (SPEAR), also have been used in an auxiliary capacity as synchrotron radiation sources, supporting a growing program in what eventually has become the second major mission of SLAC, so-called ‘photon science’. This one-of-a-kind term encompasses all use of high-intensity electromagnetic radiation for the multi-disciplinary study of materials (including biomaterials).

SPEAR, the storage ring facility commissioned in 1972 and instrumental for the discoveries of the November revolution, was gradually deserted by the particle physicists as their attention turned to new accelerator complexes on site (Table 1). In 1992, SPEAR was completely turned over to the synchrotron radiation laboratory (SSRL; Stanford Synchrotron Radiation Laboratory, now Stanford Synchrotron Radiation Lightsource), which since has run it as a dedicated synchrotron radiation source. A major upgrade (in 2002–2003) was undertaken in which SPEAR was rebuilt into a modern storage ring that secured the future of its experimental program in photon science at SLAC.

Table 1. Chronology of SLAC Machines.

	In operation	Particle physics use	Synchrotron radiation/photon science use
Linac	1966–1974	1966–1974	None
SPEAR	1972–2001	1972–1990	1974–2001
PEP	1980–1994	1980–1994	1985–1989
SLC	1989–1998	1989–1998	–
PEP-II*	1998–2008	1998–2008	–
SPEAR3**	2003–	–	2003–
SPPS	2003–2006		2003–2006
LCLS	2009–	–	2009–

*Upgrade of PEP; **Upgrade of SPEAR.

The photon science activities at SLAC today also thrive in a new experimental context, namely the operation of the world's first X-ray free electron laser (FEL), the Linac Coherent Light Source (LCLS), constructed at SLAC in 2003–2009 with the use of one-third of the original linac. A FEL is a source of ultra-intensive laser radiation suitable for studies of materials very much like those done with synchrotron radiation, but with dramatically improved performance on some selected parameters. FELs are, thus, not likely to replace synchrotron radiation facilities but rather to complement them by offering some specialised capabilities. With the inauguration of the LCLS, SLAC completed a transition from single-program particle physics laboratory to a multi-program laboratory with emphasis on photon science (and with a complementary program in particle astrophysics and cosmology). The activities of SLAC are currently dominated by its service to the scientific communities using synchrotron radiation and an FEL. At the time of this writing, SLAC is in the midst of a new major construction project that involves the conversion of another part of the original linac into an expanded FEL facility with some ground-breaking scientific capabilities, the LCLS-II.

This article records and analyses two decades of transition at SLAC, from the formal change of its mission status to include synchrotron radiation in 1992, when SSRL also was made a division of SLAC, until 2012. As a historical chronicle, this article follows Hallonsten's historical account of the first 20 years of synchrotron radiation research at SLAC in what has been called 'parasitic' mode, i.e. as an auxiliary activity completely dependent on the generosity of the particle physicists in charge of the machines whose X-rays (as by-product of the acceleration of the charged particles) these synchrotron radiation activities used.² Founded, in 1972, as the Stanford Synchrotron Radiation Project (SSRP) under the auspices of the Hansen Experimental Physics Laboratory (HEPL), an independent research laboratory at Stanford University, and evolving itself into an independent Stanford laboratory in 1977, SSRL kept close ties to Stanford University and its faculty, engaging several research groups from several schools on the Stanford campus in its scientific program.

The 20 years of parasitic synchrotron radiation activities at SLAC (1972–1992) constituted a transformation of both laboratory practices and organisation that eventually led to the broadening of the laboratory's scientific mission and a formal organisational merger of SLAC and SSRL, but the complete transition of SLAC to its current state occurred in the time period covered in the present article. As will be argued, the LCLS project especially was a major force in this transition, as was, of course, also the preceding and concurrent restructuring in particle physics on the site (as well as nationally and globally; see below) and a number of managerial and organisational strains that led to an organisational transformation some years into the new millennium. This transformation included renewal and restoration of the relations between the laboratory and its host, Stanford University, and its funder, the DOE. Thus, the overall argument conveyed here is that SLAC transformed in small steps, already beginning in the 1970s and culminating in the reinvention of the laboratory in the late 2000s.

SLAC's most recent transformation (1992–2012) started to unfold in a science policy context in which the overall federal budget for research and development was tight and in which funding priorities sharply drifted towards the life sciences at the expense of fundamental physics. Among the many federal agencies sponsoring research and development, the DOE was affected by these budget constraints, particularly in its HEP program, which was cut substantially during the 1990s. When the federal budget situation for science began

to improve in the early 2000s, a substantial part of its growth was channelled into the life sciences and adjacent fields, thus providing both direct and indirect support for the BES program at the DOE.

As the article shows, funding contexts characterised by growth constitute arenas in which institutional entrepreneurs can take initiative and convince peer scientists to join and provide support for the realisation of new scientific and technical opportunities. In addition to appropriate funding, institutional entrepreneurs need a supportive academic environment governed by mutual trust between all actors involved, particularly among research sponsors, administrators, and scientists. The upgrade of SLAC's former HEP machine SPEAR in the early 2000s, the design and construction of the LCLS, and SLAC's move into the field of astroparticle physics and cosmology are all witness to how funding contexts characterised by growth, institutional entrepreneurs striving for new scientific opportunities, and the supportive academic environment of Stanford University contributed to SLAC's transformation. It is important to note that SLAC managed to redeploy scientific and technical capabilities both in photon science and in astroparticle physics and cosmology that had been built up when HEP was the laboratory's dominant scientific program.

Yet, SLAC's most recent history also illustrates that budgetary constraints in the field of HEP led to underinvestments in the management of safety, environment and health that culminated in a safety crisis and created considerable tensions among research sponsors, administrators and scientists – a crisis that ultimately threatened the survival of the whole laboratory. However, SLAC leadership managed both to establish a new safety culture and to accommodate the laboratory's organisational structure to its changed mission and research programs. Continued performance improvements in laboratory management and a reconsideration of rules and responsibilities re-established mutual trust among the DOE, Stanford University and the SLAC leadership.

The article draws on the following data sources: (1) material from the SSRL/SLAC's archives and websites; (2) material from Stanford University's archives and websites; (3) material from the DOE and other National Laboratory websites; (4) newspaper articles; (5) material from 11 interviews conducted in 2007, 2012 and 2013; and (6) secondary literature.

The structure of the article is as follows. First, we describe the science policy context in the United States in the 1990s and 2000s, with special emphasis on changes in the federal science budget. Then, we describe how research with synchrotron radiation became more deeply embedded in the laboratory, how the new LCLS facility was planned and ultimately constructed and operated, how the shift towards non-accelerator astroparticle physics and cosmology was accomplished, and how a safety and management crisis gave additional momentum to the laboratory's transformation. Finally, we summarise our results and draw science policy conclusions.

2. Science policy context in the United States: 1990s and 2000s

In the last third of the twentieth century, the Cold War logic of superpower competition in nuclear energy and weaponry as well as other areas was succeeded by a different science policy regime that resonated with globalisation and the emergence of so-called grand challenges of medical, ecological and social sustainability.³ This transition occurred on a global stage, but in the United States as the global scientific superpower, the change was particularly visible when the Superconducting Super Collider (SSC), the particle physics

community's next large accelerator project, was terminated prematurely in 1993 whereas the Human Genome Project was continued and eventually followed by the launch of the National Nanotechnology Initiative and the doubling of the annual budget of the National Institutes of Health (NIH; see below).⁴ But the termination of the SSC was only the culmination of a development that had been ongoing since the 1960s: within the field of particle physics, a concentration of efforts to fewer national centres occurred, spurred by the growth in size of the accelerator complexes necessary to maintain the pace of discovery, and this created a 'mission vacuum' for several of the national laboratories, most prominently Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Argonne National Laboratory and Oak Ridge National Laboratory. These had been powerhouses of US fundamental physics in the 1950s and competed on world stage with their particle physics programs, but as their flagship machines grew old and were taken out of operation, they had to find new alternative uses of large scientific facilities. All made important contributions to the development of the use of accelerators to produce synchrotron radiation, and the use of reactors and accelerators to produce neutrons for the study of materials.⁵ When the SSC was cancelled in 1993, Brookhaven was already operating the National Synchrotron Light Source (NSLS), Argonne and Berkeley were building major federally funded synchrotron radiation facilities of their own, and Oak Ridge was engaged in the planning for the next big neutron facility that would become the Spallation Neutron Source, SNS, starting operation in 2007.

US federal science funding in the 1990s was shaped by considerable efforts of the two Clinton administrations (1993–2001) to reduce the annual federal budget deficit and the national debt. Furthermore, following the mid-term election in 1994, when Democrats had lost their majority in both houses of Congress, Republicans enacted sharp reductions in publicly funded research and development, beginning with the 1995 federal budget.⁶ In fact, between 1990 and 2000, the federal annual appropriations for research and development declined from \$92.3 billion to \$82.9 billion in constant 2009 dollars.⁷ Consequently, additional resources in research and development had to be generated 'through productivity gains rather than through increased budgets'.⁸ The decline did not hit all science fields equally. For example, while the federal spending for energy research plummeted between 1992 and 1997 from \$3.4 billion to \$2.3 billion, the funding for health-related research increased from \$10.9 billion to \$12.4 billion.⁹ The DOE was hit particularly hard and 'did not receive significant funding increases for over a decade'.¹⁰

In this funding environment, the cancellation of the SSC occurred. Back in 1988, the SSC had been approved at a cost estimate of approximately \$4 billion.¹¹ Yet, when five years later estimated costs had risen to over \$10 billion, the US Congress decided to cancel the project even though 22 km of accelerator tunnel (about a fourth of the full planned length) had already been dug at the Texas site at a cost of \$2 billion. In addition to the soaring costs, several other factors contributed to the SSC's cancellation, including the selection of a site for the machine in Texas, far from existing federal particle physics laboratories, tensions among the DOE, the scientific communities and elites over the management of the project, and not least a generally dwindling political support for similar undertakings that ultimately had to do with the end of the Cold War.¹² The congressional decision signalled to the particle physics community that their branch of governmentally sponsored R&D was not going to continue to enjoy the unlimited support as in previous decades and that they had to readjust their priorities.¹³

In fact, in the late 1990s, the second Clinton administration started increasing federal appropriations for health-related research at an unprecedented scale, an effort that was later continued by the first administration of G.W. Bush. Between 1998 and 2003, the funding for health-related research climbed from \$13.1 billion to \$23.4 billion.¹⁴ This increase meant that while the NIH budget doubled, other science agencies experienced marginal increases only.¹⁵ In the mid-2000s, the tides seemed to change when, in response to what was perceived as an unbalanced federal science budget, the G.W. Bush administration started to increase budgets in the physical sciences and engineering again.¹⁶ There was an ‘increased recognition that the nation could no longer neglect the physical and other nonbiomedical sciences.’¹⁷ Yet, although this increase happened in nominal terms, it did not translate into inflation-adjusted growth. Between 2000 and 2012, the federal budget for the physical sciences remained flat at \$5.9 billion in constant 2009 dollars.¹⁸ In contrast, the entire federal science budget increased by more than 50% between 2000 and 2009, from \$82.9 billion to \$127.2 billion. Then, in 2010, the federal budget started to decrease again and reached \$118.8 billion in 2012.¹⁹

Inside the DOE, both the decrease in federal science spending in the 1990s and the increase in the 2000s, and the priority changes from the physical sciences to the life sciences were translated into shifting resources between its HEP and BES programs. Between 1985 and 2014, the former decreased from roughly \$1.0 billion to \$650 million, while the latter increased from \$750 million to \$1.4 billion (Figure 1). Therefore, the funding of SPEAR3 and LCLS, both of which were mainly funded from the BES program (Sections 3 and 4), took place in a growing funding regime, despite the overall stagnation of funding for the physical sciences.²⁰

Today, the DOE is the fourth largest sponsor of research and development in the federal government and the leading sponsor of research in the physical sciences, behind the Department of Defence, the NIH and the National Aeronautics and Space Administration; its science funding is administered predominantly through the Office of Science, which is overseen and directed by an undersecretary for science, a position appointed by the President and confirmed by the Senate.²¹

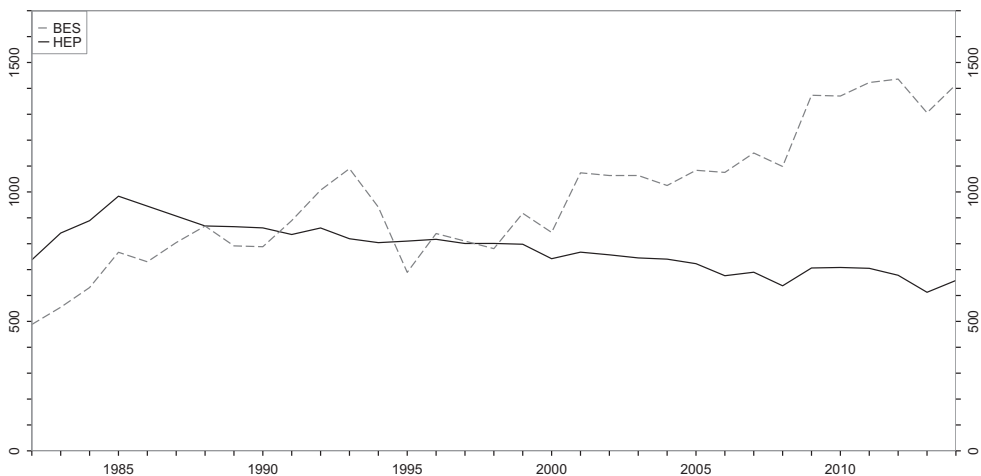


Figure 1. Funding Streams by the Department of Energy, 1983–2014: real budgets in constant 2005 US dollars (Mio.); Source: DOE 1984–2016.

3. Integration and growth of synchrotron radiation research

The beginning of SLAC's transformation can be traced to the 1970s, when synchrotron radiation started as a parasitic research activity at the SSRP, and later SSRL. Yet, SSRL's merger with SLAC in 1992, and thus, the formal recognition of synchrotron radiation research as a legitimate organisational mission of SLAC, is a good starting point for analysing how SLAC changed from a once-leading HEP laboratory into one in which photon science (and non-accelerator-based astroparticle physics and cosmology) gradually took over and became the laboratory's core field. The 1992 merger of SSRL and SLAC had been preceded by years of discontent among users and SSRL staff with the priorities on the SLAC site. On the initiative of the DOE and with the active help of SLAC director Burton Richter, the relationship between the two laboratories was re-examined through a series of studies, all of which seemed to conclude that preservation of status quo was preferable, citing the radically different cultures of the laboratories, their unequal standing in terms of budget volume and physical assets, and several administrative obstacles to a merger. But wheels had apparently been set in motion, and in 1989, a study recommended a merger of the laboratories, the creation of a special SSRL division of SLAC, and the promotion of the SSRL director to associate director of SLAC.²²

Before the merger, the relationship between the two laboratories and Stanford University was as follows:

SSRL is an independent laboratory that formally reports to the Dean of Research. SLAC, on the other hand, reports to the President except on academic issues where the Director reports directly to the Provost. In this case, SLAC acts like a School.²³

After the merger, when SSRL had become a division of SLAC, its relationship to Stanford University was streamlined towards the President's and the Provost's offices. This change in the formal relationship with Stanford University already meant that synchrotron radiation came to be on par with HEP because now SSRL issues would be discussed on a regular basis between the Stanford President and Provost on the one hand, and the SLAC director on the other hand. In addition, several other aspects are witness to the increasing integration of synchrotron radiation research at SLAC since 1992.

To begin with, the SSRL director coordinated not only synchrotron radiation research in SLAC's new SSRL division, but also as an associate laboratory director, he had full responsibility to participate in the long-range planning activities for the entire laboratory. Second, the two separate oversight bodies, SLAC's Science Policy Committee and SSRL's Science Policy Board, were merged into the new Science Policy Committee, whose charge was broadened and included both programs in its purview.²⁴ Third, and perhaps most important, SSRL received its own budget line from the DOE's Basic Energy Science program in addition to SLAC's regular HEP budget. Separating the BES and HEP budget lines provided scientific independence for SSRL and thus, satisfied one important principle that had guided the merger negotiations.²⁵

In addition to being formally on par with SLAC's HEP program, synchrotron radiation gained a more prominent role in the laboratory's research strategy. Earlier reports outlining SLAC's research strategy had been relatively silent on 'SSRL' and 'synchrotron radiation', but that changed dramatically in 1992. Before the merger, these two terms were mentioned about 20 times in each planning document.²⁶ After the merger, they were mentioned more than 170 times.²⁷ The increased number of mentions included descriptions

of the broad spectrum of synchrotron radiation research conducted at SPEAR in the early 1990s and an appraisal of SLAC's former HEP machine SPEAR, which is characterised as being among the 'most modern of the world's presently operating X-ray synchrotron radiation'.²⁸ Furthermore, SLAC's leadership started to highlight a convergence of technical and scientific interests between the fields of HEP and synchrotron radiation, and it portrayed the two programs as allies.²⁹

Perhaps most important, the integration of synchrotron radiation in SLAC's overall research strategy came with two infrastructural changes on the SLAC site. First, the detachment of the SPEAR ring from the main SLAC linac and the construction of a separate injector for SPEAR meant not only a partially new technical optimisation of the accelerator complex used by SSRL but also that SSRL was put in charge of maintenance and operations of SPEAR. This duty included its continuous technical refinement and all choices regarding its operations and how to best optimise its performance to meet the demands of its user communities.

A second development concerned the Positron Electron Proton Ring Accelerator (PEP)-II, also called B-Factory, which was a new SLAC flagship machine dedicated to HEP. In February 1993, at a time of tight federal budgets for the physical sciences (Section 2), SLAC Director Burton Richter presented the DOE what could be called an all-or-nothing option:

the Stanford Linear Accelerator Center faces a crucial transition (...). It must either renew its facilities to maintain its vitality and continue offering unique research opportunities, or begin an inevitable decline that will amount to a major loss for U.S. science.³⁰

In Richter's argument for PEP-II, synchrotron radiation for the first time functioned as witness for the defence of a new particle physics machine. He claimed that PEP-II would not only advance SLAC's HEP program but also find a new productive use as machine for synchrotron radiation. Therefore, he invoked a future for PEP-II similar to that of SPEAR, namely that once 'outdated for particle physics research' it would be 'recycled into other productive ends', meaning synchrotron radiation, and asserted that without providing funding for PEP-II, the 'health of the synchrotron radiation program will also suffer'.³¹ As will be shown below, the DOE decided to fund PEP-II at SLAC (Section 5).

The increasing integration of SSRL into SLAC did not change SSRL's close relationships with various academic departments at the Stanford campus. During the merger negotiations, SSRL faculty had raised concerns that integrating SSRL into SLAC would turn SSRL faculty away from Stanford.³² Therefore, the 'New Constitution for the Faculties of the Merged SLAC-SSRL' endorsed the recommendations of the 'Special Committee on Appointments at SSRL', chaired by Walter Falcon (Stanford University), in which the close relationship between SSRL and Stanford was highlighted and discussed.³³ First of all, the Falcon Report pointed out that SSRL's scientific strength 'must come through judicious new hires, coupled with strengthened links to Stanford University departments'.³⁴ This recommendation was based on successful experience, as Arthur Bienenstock outlined:

Various departments cooperated with us because they saw the opportunity of hiring someone who was very good in chemistry or structural biology. (...) In the early days, it was the departments of Applied Physics and Electrical Engineering that were the most helpful.³⁵

When hiring new faculty, the Falcon Report recommended 'that SSRL and Stanford use joint appointments to serve best their individual and combined needs'. In addition, it recommended 'part-time appointments of existing faculty in academic departments that

can be made at SSRL for defined and limited periods of time.³⁶ Most important, the Falcon Report refers to the existing situation of SLAC as a role model for SSRL: ‘the Committee believes that SSRL faculty needs expansion to provide a depth similar to that at SLAC.’³⁷

Although SSRL’s strategic importance for SLAC had been acknowledged and its ties to the Stanford campus remained intact, the tight federal science budgets in the early 1990s (Section 2) posed a challenge to the integration of both research programs under the roof of one laboratory. In 1994, the DOE imposed a freeze on wages and salaries at contractor laboratories, effective in 1995. Richter informed all SLAC employees that the DOE ‘has already reduced our funding by an amount which, by their estimate, is that which we would need to give normal raises to all SLAC employees.’³⁸ The total inflation-adjusted DOE budget for SLAC declined between 1995 and 2000 from \$240 to \$205 million (Figure 2). However, the federal cuts affected the HEP and BES budgets differently: the former declined from approximately \$220 to \$175 million, while the latter increased from \$20 to \$30 million. Accordingly, in 1996, SLAC had to accept staff reductions in its HEP program of about 80 (± 10) positions, but at the same time, SSRL’s staff increased by 20 positions. A total of 40 SLAC employees chose to be laid off voluntarily, and another 28 received notification of their involuntary layoff.³⁹ At the same time, employees from the HEP program were encouraged to apply at SSRL. In 1997, another 70 staff positions in HEP had to be eliminated.

Following these budget cuts, the high expectations regarding SLAC’s future HEP program were clearly disappointed. While in the late 1980s, an increase in the total number of mostly HEP staff from 1470 (1988) to 3027 (1995) was foreseen (thus, more than a doubling), these estimates were drastically adjusted downwards to 1543 (1998) a few years later.⁴⁰ Richter concluded that ‘SLAC has a bright future, but it will be somewhat smaller in 2000 than it is now.’⁴¹ As will be argued below, these staff reductions, particularly in SLAC’s technical division, are one possible reason why SLAC experienced major difficulties in its environment, safety and health performance in the late 1990s and early 2000s (Section 6).

The budget cuts had consequences also for SSRL because at that time, SPEAR could be operated for six months only; thus, more than 50% of the requested experiments could not be scheduled.⁴² Therefore, the Science Policy Committee endorsed ‘the efforts of Professor

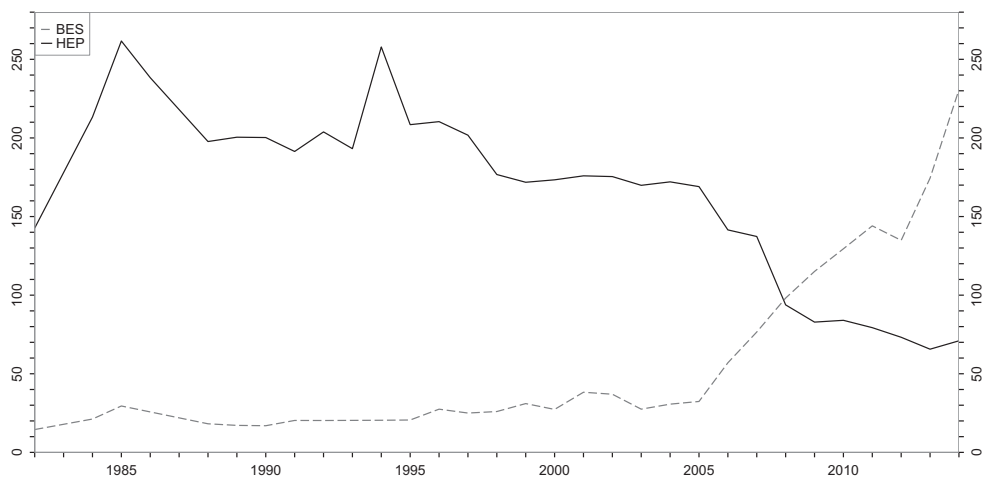


Figure 2. Funding Streams by the Department of Energy for SLAC, 1983–2014: real budgets in constant 2005 US dollars (Mio.); Source: DOE 1984–2016.

Bienenstock (...) to increase the operating funds'.⁴³ In 1995, the SSRL leadership argued that one of the largest constraints to meeting user's needs was funding for operating time.⁴⁴ Nevertheless, and in contrast to SLAC's HEP program, SSRL continued to grow in terms of experimental stations and users. In 1994, there were approximately 700 users from 147 universities and other research laboratories, both public and private.⁴⁵ SSRL received proposals predominantly from materials sciences (38%) and the life sciences (38%), and from the geosciences and ecology (9%), applied sciences and engineering (7%), chemical sciences (6%), and facility instrumentation (2%).⁴⁶ The most highly subscribed field was structural biology, for which a new beamline was under construction in the mid-1990s, with support from the DOE.⁴⁷ The new structural biology beamline provided three experimental stations designed for protein crystallography and X-ray absorption spectroscopy.⁴⁸ In 1995, SSRL had already about 950 users from 145 universities and other research laboratories.⁴⁹ The same year also saw several significant accelerator improvements which led to increased beam stability and continued reliability.⁵⁰ In 1996, therefore, when budget pressures were somewhat relieved, the number of SSRL users jumped to almost 1100.⁵¹

Despite its overall growth, SSRL's future had become somewhat uncertain in the late 1990s because two new synchrotron radiation facilities had been taken into operation in the United States: the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory, in 1993, and the Advanced Photon Source (APS) at Argonne National Laboratory, in 1995.⁵² Hence, the Science Policy Committee argued: 'If SSRL is to survive after 1999, it will be necessary to further enhance the user program with outstanding scientific and technical efforts, more specifically new beamlines and new sample preparation laboratories.'⁵³

Arthur Bienenstock, director of SSRL between 1978 and 1998, claims that challenges of various kinds threatened the success and sheer existence of the SSRL several times and that this situation changed only as the new millennium drew nearer: 'We were orphans. And I would say that that remained the case until the Birgeneau-Shen Committee'.⁵⁴ This committee was set up, following the DOE's Office of Science assignment for its BES Advisory Committee (BESAC), to assess the need for its four synchrotron light sources. It was chaired by Robert J. Birgeneau (Massachusetts Institute of Technology) and Zhi-Xun Shen (Stanford University) and submitted its report in August 1997.⁵⁵ The report concluded 'unanimously that shutdown of any one of the four DOE/BES synchrotron light sources over the next decade would do significant harm to the Nation's science research programs and would weaken our international competitive position in this field'.⁵⁶ Most important, SSRL was given the highest priority among all synchrotron light sources. The panel 'was very impressed by [its] outstanding performance' and by SSRL's capability to 'continue cutting-edge research even though the storage [ring is] not the most advanced'.⁵⁷

Interestingly, the Birgeneau-Shen Report seems to have delivered the opposite of what many had expected. SSRL director Arthur Bienenstock, 'fearing a backroom decision to shut down the SSRL', remembers having been very active in pressing for the review so that there would be a transparent and open evaluation of the performance of the four laboratories.⁵⁸ The DOE was, reportedly, surprised by the outcome, as it was possibly oriented to closing the SSRL and redirect funding to the ALS and APS but now obliged to make a different decision and let SSRL live.⁵⁹ In a 1997 news report in *Science*, the co-chair of the panel, Zhi-Xun Shen, motivated the low grades for the ALS with its unexpectedly low return for investment, noting that the ALS had a 50% larger budget than SSRL but less than half the number of users.⁶⁰ The report allegedly 'stunned ALS officials, who had expected that their

\$100 million machine would sail through the review,' and within a few weeks, the ALS budget was cut by 10%, and a number of scheduled upgrades were postponed until proof of improvement could be seen. In 2000, a follow-up study confirmed clear progress in meeting the demands implicitly made in the Birgeneau–Shen assessment, and the laboratory was allowed back to ordinary levels of funding.⁶¹

But SPEAR was old. Taken into operation for HEP experiments in 1972, it had been operating for 25 years. Furthermore, it was never designed to produce synchrotron radiation and was, therefore, technically outrun by most other synchrotron radiation facilities worldwide, and in the United States (most notably the ALS and APS), that had been designed and constructed using the vast technological advances and organisational innovations that the field of synchrotron radiation facilities had developed in the 1970s, 1980s and 1990s.⁶² SPEAR was, in short, in desperate need for an upgrade to keep up with competition and remain as strong in science as the Birgeneau–Shen Report had found it to be (see above).

Preparations for the upgrade started in January 1997 with the forming of a study design group. In May 1997, an SSRL users workshop 'examined the benefits of SPEAR 3 in terms of enhanced photon flux density and brightness' and concluded that the 'new opportunities for science and technology (...) provide compelling reasons to proceed in the most rapid way possible with the SPEAR 3 upgrade.'⁶³ In November 1997, the preliminary conceptual design report was reviewed by a panel of outside experts; in May 1999, the DOE granted project approval, and construction started.⁶⁴ In March 2003, SPEAR 2 was shut down and the installation of the SPEAR 3 components began.⁶⁵ Final operation approval was granted by the DOE in November 2003, and by March 2004, SPEAR 3 was fully operational (Figure 3).⁶⁶

The total costs of the SPEAR 3 upgrade were \$58 million, a modest sum compared to the \$100 million that had been necessary to build the ALS, the eventual LCLS construction budget of over \$400 million (Section 4), and the costs for the Spallation Neutron Source at Oak Ridge National Laboratory, which landed on a stunning \$1.4 billion.⁶⁷ Especially, the life sciences program was predicted to receive a boost from the SPEAR upgrade, and reportedly, there was strong pressure from biology users and the NIH that really helped

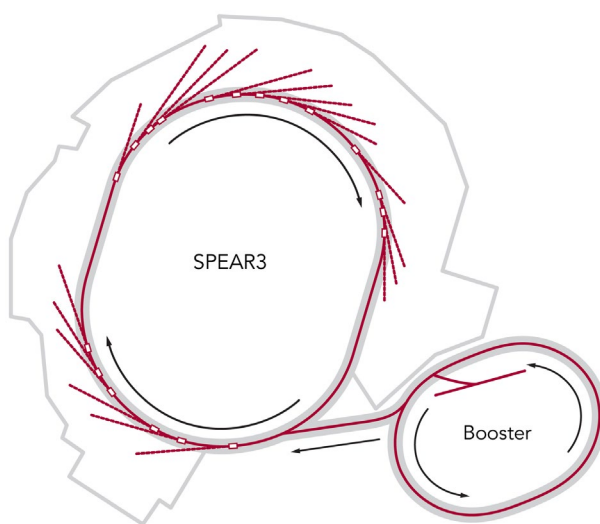


Figure 3. Stanford Positron Electron Asymmetric Ring (SPEAR 3); Source: SLAC National Accelerator Center.

push the SPEAR3 project to funding.⁶⁸ Eventually, the final bill of \$58 million was split in half between the NIH and the DOE.

By the year 2000, 'SSRL counted more than 1900 researchers on active proposals from industry, government laboratories and universities, 1624 of whom were involved in the 370 proposals receiving time for 765 individual experiments.'⁶⁹ At that time, SSRL operated 8–9 months per year, and beams were delivered almost 97% of the time scheduled.⁷⁰ Since SPEAR3 had become operational in 2003, the number of users had grown again, and by the end of the 2000s, reached a new peak with about 2000 users.⁷¹ After the LCLS had successfully started its operations (Section 4), SSRL's users stood at 1500.⁷² Together with the LCLS users, the photon science user community at SLAC was at an all-time high.

4. Building the laboratory's future: the Linac Coherent Light Source (LCLS)

As argued above, SLAC's overall transition to photon science had gained momentum with the dedication of SPEAR to synchrotron radiation research in 1992 and its subsequent conversion to a third-generation light source in 2003. However, the increasing competition from other third-generation light sources in the United States (ALS, APS) and the gradual emergence of an entire organisational field of synchrotron radiation facilities worldwide led both photon scientists and accelerator scientists to develop a research strategy that would go beyond SPEAR3 and in which the SLAC would have a competitive edge over other photon science laboratories.⁷³

In February 1992, and thus a few months before SSRL merged with SLAC, the concept of a FEL was discussed during a workshop at SLAC on 'Fourth Generation Light Sources', which was organised and chaired by Max Cornacchia and Herman Winick.⁷⁴ It was at this workshop that Claudio Pellegrini (UCLA) proposed to rebuild the SLAC linac into a FEL.⁷⁵ A study group was formed that soon began drafting a project that proposed extensive research and development on the subject matter. In June 1992, the name 'Linac Coherent Light Source' was introduced, and in the same month, the group submitted its project proposal to the DOE, requesting \$100,000 as a planning grant.⁷⁶ An expert panel strongly endorsed the proposal: 'If no resources are provided for the development of the Conceptual Design Report and the benchmarking experiments, important scientific opportunities may be missed'.⁷⁷ Another workshop on 'Scientific Applications of Short Wavelength Coherent Light Sources' was organised on 21 October 1992.⁷⁸

Claudio Pellegrini, Max Cornacchia and Herman Winick can be regarded as scientific pioneers at the frontier of X-ray FEL development: they inspired other scientists both in the synchrotron radiation and accelerator communities to join the FEL study group. At the same time, they were able to convince the DOE to invest in what at that time was regarded as a risky project. Their activities reflect in many ways the entrepreneurial culture of Stanford faculty more generally.⁷⁹ It should also be noted that SLAC's leadership supported the project. Following the various workshops, the study group meetings, and the successful project proposal, Burton Richter understood that SLAC was in a unique position to build a FEL because it had developed scientific and technical capabilities in its HEP program that turned out to be very valuable for that purpose.⁸⁰ In one sense, this renewal on basis of existing capabilities was similar to what other National Laboratories undertook in the face of 'mission vacuum' from the 1970s and on (Section 2), but it can also be argued that the LCLS initiative was bolder in its scientific ambitions than the new projects developed at

Argonne, Berkeley and Brookhaven in the 1970s and 1980s, which built more on established scientific use of synchrotron radiation (and neutrons), and took smaller technical risks.⁸¹

In the following two years, several workshops were held that dealt with particular questions and technical design features of the LCLS, including 'Towards Short Wavelength FELs Workshop', 21–22 May 1993, and 'Workshop on Scientific Applications of Coherent X-Rays', 12 February 1994.⁸² In February 1993, the LCLS group submitted a 'Construction Project Short Form Data Sheet' to the DOE where the total costs of the LCLS were estimated at about \$29 million. The DOE forwarded the LCLS group's request to the National Academy of Sciences, which set up a 'Committee on Free Electron Lasers and Other Advanced Coherent Light Sources' in 1994.⁸³ Yet, the committee recommended that more research and development be done before the construction of the LCLS could be undertaken.⁸⁴

This recommendation was emblematic of the scepticism that existed regarding the technical and scientific feasibility of the LCLS: 'The main concern was that the very high X-ray intensity would blow up any sample on the beam path, making it impossible to obtain useful data.'⁸⁵ For example, at a workshop on fourth-generation light sources in Grenoble (France), 22–25 January 1996, there was a lively debate on the subject matter and several prominent French X-ray scientists said the LCLS would never work.⁸⁶ In addition to 'combined scepticism of many X-ray and FEL scientists on the practicality and feasibility of the X-ray FEL project', there was little initial interest on behalf of those for whom the LCLS would have opened new exciting research opportunities.⁸⁷ Biologists had 'no interest in an expensive X-ray laser'.⁸⁸ Moreover, 'the users were perfectly happy with synchrotron radiation. They did not call for an X-ray free electron laser. The community was not ready for LCLS'.⁸⁹ However, the initial scepticism gradually gave way to a more supportive attitude once results from preliminary studies of some key technologies of X-ray FEL became available, which were regarded as proofs-of-principle.⁹⁰

In the meantime, the scientific and technical review process that finally led to the LCLS's construction got underway. In August 1997, the Birgeneau–Shen Report recommended 'modest investment in research and development of a fourth-generation X-ray source'.⁹¹ This recommendation led the DOE's Office of Science charge the BESAC to prepare a plan regarding the future development and application of synchrotron radiation sources. The BESAC set up a panel on novel coherent light sources that submitted its report in January 1999 to the BESAC which unanimously accepted its recommendations in February 1999.⁹² The BESAC panel report pointed out that 'DOE should pursue the development of coherent light source technology in the hard X-ray region as a priority'. It also recommended providing provisional support 'for a highly focused and fiscally responsible set of investigations to determine the feasibility and design of a 1.5 Angstrom coherent light source' and suggested that SLAC and other partners 'should assume the lead role of formulating the necessary experimental steps'.⁹³

When the Birgeneau–Shen Report had been issued, the LCLS project group started drafting a design report which was made available in 1998 and thus before the BESAC recommendation in February 1999.⁹⁴ The LCLS project group's efforts were reviewed positively by SLAC's Science Policy Committee, which reiterated in 1997 its 1994 recommendation for the project.⁹⁵ The group's activities bore fruit when the DOE accepted BESAC's recommendations and provided initial funding for additional research and development that was necessary to prepare a full conceptual design report for LCLS, 'a very important moment in the history of LCLS and in general of X-ray FELs'.⁹⁶ With the new funding from

the DOE, a multi-institutional collaborative LCLS design team was set up that involved scientists from SLAC, Argonne National Laboratory, Brookhaven National Laboratory, Los Alamos National Laboratory, Lawrence Livermore National Laboratory and the University of California at Los Angeles.⁹⁷ In 1999, both a Technical Advisory Committee and a Scientific Advisory Committee (SAC) were formed to advise SSRL and SLAC's technical division on LCLS-related issues and review the program's progress.

It is noteworthy that,

the accelerator guys really drove the idea. They were excited about a new application for accelerators. They didn't know much about X-ray science but they could certainly see that if you can build a source that advances the capability by nine orders magnitude, that might have some application. They were the ones that were pushing it.⁹⁸

Most important, when the SAC had to select scientific experiments for the test phase of the LCLS project, photon scientists had to think hard about what the possible research projects could be: 'They gave us a new source. What the hell are we going to do with this? We had no clue. We were completely unprepared.'⁹⁹ The major difficulty for the synchrotron radiation community at SLAC was the fact that there seemed to be almost no one at Stanford campus who knew what to do with an ultrafast light source:

LCLS comes along with femtoseconds. (...) What you can do with that is study things very fast. You look around at the university and you say who is interested in ultrafast science? Big zeros. Nobody on campus is really doing ultrafast science. Not on that time scale.¹⁰⁰

Together with accelerator scientists, photon scientists selected the following fields for the test phase of the LCLS: atomic physics, plasma and warm dense matter, structural studies on single particles and biomolecules, femtochemistry and nanoscale dynamics in condensed matter physics.¹⁰¹ Based on the report of these test experiments, in June 2001, the DOE's Office of Science approved the mission need for the LCLS. In January 2002, the LCLS design study group submitted its LCLS Design Report to the DOE.¹⁰² The report had 111 authors from 29 universities and non-university research institutes, and it estimated that the total project costs would be in the range of \$185–245 million and that construction would take approximately three years.¹⁰³

In February 2002, a DOE review of the LCLS project was initiated.¹⁰⁴ The report of this review was delivered in April 2002 and recommended going forward.¹⁰⁵ In October 2002, the DOE granted to start the project engineering design, so the concrete planning could move ahead. This decision was not meant to prepare the engineering design of a test facility because an ultraviolet FEL test facility had already started its operations at DESY in Hamburg, Germany, in 2001.¹⁰⁶ Rather, the DOE wanted a full-scale hard X-ray FEL user facility.¹⁰⁷ In February 2003, the LCLS project received another positive review by the BESAC's Subcommittee Workshop Report on the '20-Year Basic Energy Sciences Facilities Roadmap' which argued that the LCLS offers 'exciting new prospects for future scientific endeavors in BES' and that it receives 'highest recommendation for strong continued support'.¹⁰⁸

The years 2003–2005 were dedicated to building technical components, preparing long-term procurements and accomplishing all functional requirements of the DOE critical decision process. During these years, the SLAC linac was used for the Sub-Picosecond Pulsed Source (SPPS), an ultrafast X-ray source parasitic to B-factory operation. This experimental X-ray source (not a FEL) provided important early experience with ultrafast X-ray pulses, and in particular with synchronising an ultrafast X-ray source with ultrafast optical lasers (Table 1). In August 2005, the DOE granted approval of construction for the LCLS. One year

later, in October 2006, an LCLS ground-breaking ceremony was held at the SLAC site.¹⁰⁹ The start of commissioning was celebrated 13 April 2007, operations started in April 2009, and the first user experiments were performed in October 2009 (Figure 4).¹¹⁰

When the LCLS started its operation, it exceeded expectations in many respects. First, its reliability was 95% beam uptime in capability.¹¹¹ Second, just a few years into the operational phase of this new facility, its ‘scientific impact has already been profound,’ spanning a broad range of research fields, including life sciences, plasma physics, magnetism, chemistry, materials science, atomic physics and surface science.¹¹² Third, the LCLS also exceeded expectations as to how many users would be interested in conducting their experiments at the new light source – given the low interest only a few years earlier. In 2009, the LCLS ‘received 551 proposals for beam time involving more than 1400 unique users. On average, LCLS is oversubscribed by 400%.’¹¹³ The considerable scientific opportunities at LCLS are also reflected in SLAC’s most recent long-range planning document in which it is called ‘the future of SLAC’.¹¹⁴

In contrast, SLAC’s mission statement in the same document does not contain ‘high-energy physics’ anymore. However, it would be wrong to conclude that the scientific and technical competences of accelerator-based HEP were made redundant. Quite the opposite is true for the LCLS:

we realised that the particle physicists at SLAC had incredible detector expertise. We pulled half of them into LCLS. We realised that people in high-energy physics have expertise with big data. LCLS writes as much data onto computer disc as the ATLAS-detector at CERN. We pulled a big fraction of the controls and data acquisition people out of the Particle and Astroparticle and Cosmology Directorate over into the LCLS Directorate.¹¹⁵

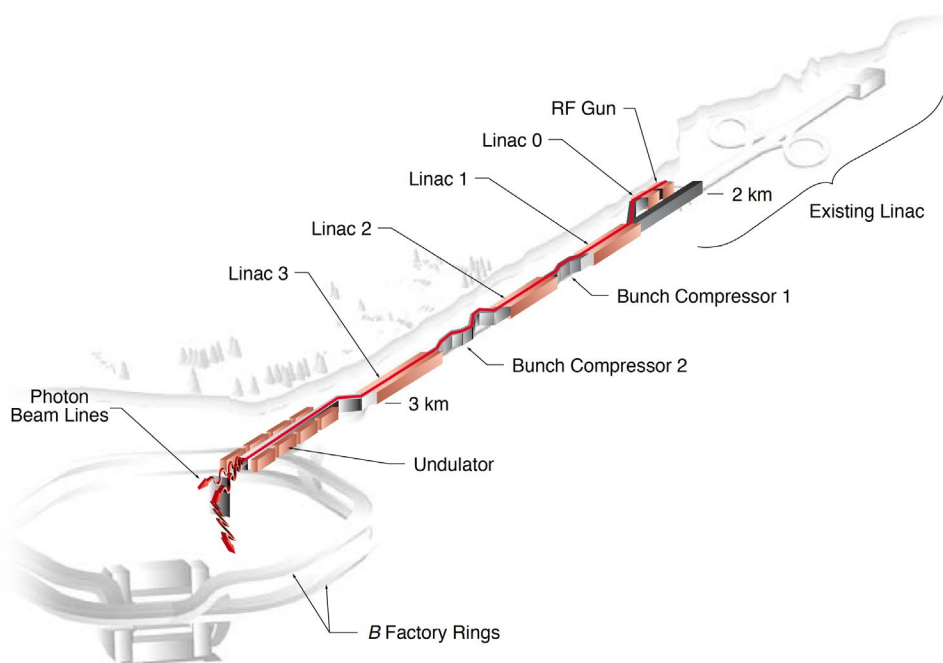


Figure 4. Linear Coherent Light Source (LCLS); Source: SLAC National Accelerator Center.

The successful construction and building of the LCLS facility ‘really broke down the walls between photon science and accelerator physics.’¹¹⁶ Therefore, the move towards photon science was made possible by several of SLAC’s high-energy physicists and accelerator scientists and engineers migrating into the LCLS Directorate.

5. Moving towards non-accelerator-based astroparticle physics and cosmology

SLAC’s transformation included not only the integration of an extended synchrotron radiation research program into the laboratory’s mission (Section 3) and the design and construction of a new and ground-breaking photon science user facility (Section 4) but also the shift from accelerator-based HEP to non-accelerator-based astroparticle physics and cosmology. This shift is important because it meant the scientific and technical capabilities that had been built up when the HEP was the laboratory’s dominant scientific program could be transferred and applied in an adjacent scientific field.¹¹⁷ In the late 1980s and early 1990s, it was not obvious that SLAC would shift its existing research program in HEP in this direction, but both budgetary constraints and new scientific opportunities provided the momentum for this shift.

Back in the late 1980s, it was inconceivable for high-energy physicists at SLAC that their laboratory would be operated without a large accelerator for HEP. Planning for the so-called B-factory, a collider designed to produce and study ‘B-mesons’, an elementary particle with especially interesting qualities, had begun already in the 1980s. The SLAC B-factory was an upgrade of PEP with the name PEP-II (Table 1). As the dust settled after the cancellation of the SSC, the process to get the B-factory funded at the federal level intensified. In its evaluation of the two competing proposals from SLAC and Cornell, the DOE not only pointed to budgetary and construction-related risks in the Cornell proposal but also considered that

SLAC is the premier US laboratory in electron physics. (...) In a fashion unlike that of Cornell’s Laboratory of Nuclear Studies, the fate of SLAC and its personnel will be strongly impacted by this decision. Selecting SLAC for the B-factory would maintain the laboratory’s vitality and preserve its world leadership in high-energy accelerator physics.¹¹⁸

The DOE decision had two effects. First, it helped SLAC continue its accelerator-based HEP program at a time when the laboratory’s mission became broader and embraced synchrotron radiation research (Section 3). Second, it ‘partially cushioned’ – as Burton Richter put it – the decreasing operating budget in HEP.¹¹⁹ The decreasing operating budget for HEP became a major concern for the SLAC leadership in the late 1990s. In 1997 and 1998, Burton Richter openly criticised the ‘curtailment of very productive research programs’ due to a ‘shortage of funds that might preclude full utilization of the facilities.’ He argued that ‘this problem is particularly acute in high-energy physics.’¹²⁰

In the fall of 1998, in the year when PEP-II became operational, Richter retired from his position after 15 years in office (Table 1). According to the *San Francisco Chronicle*, Richter nominated Jonathan Dorfan as his successor, and his recommendation ‘was unanimously supported by the university’s search committee.’¹²¹ It is also noteworthy that Dorfan was offered the position of director of Fermilab at about the same time.¹²² Dorfan had worked at SLAC since 1976 and been group leader of ‘Experimental Group C’ since 1986 and an associate director and project director for PEP-II since 1994.¹²³

The diverging budget development in HEP (decreasing) and photon science (increasing) continued through the 2000s. Dorfan had to announce that the HEP budget for the year 2000 ‘falls short of covering the cost of inflation’ requiring, what he called, a ‘careful management of attrition’, which basically meant that new hires were put on hold.¹²⁴ At the same time, and in contrast to the situation in HEP, ‘the SPEAR3 and LCLS projects are expected to continue on track and new initiatives in molecular environmental science, correlated materials and structural biology will provide for some staff and program growth.’¹²⁵ In 2002, Dorfan ‘asked the associate directors in all divisions except SSRL to examine all job requisitions very carefully, and to approve only those that are absolutely essential for the smooth running of the Laboratory.’¹²⁶ In 2003, the situation was very similar. However, when the efforts for the LCLS construction increased in the mid-2000s, some of the scientific and technical capabilities formerly built up in the HEP program were redeployed in photon science, as Dorfan explains: ‘The movement of staff from the high-energy physics to the LCLS program (...) has significantly helped to hold down staff reductions.’¹²⁷

However, scientific and technical capabilities from SLAC’s accelerator physics program were redeployed not only in accelerator-based photon science (Section 4) but also in the field of non-accelerator-based astroparticle physics and cosmology. SLAC initiated an astrogravity research program in the mid-1990s and thus, paved the way for the full transition into astroparticle physics in the 2000s. It is noteworthy that the field of astrophysics and cosmology has been very vibrant during the 1990s, culminating in the discovery of the accelerating expansion of the universe that won Saul Perlmutter (UC Berkeley), Brian Schmidt (Australian National University, Weston Creek) and Adam Riess (Johns Hopkins University) the 2011 Nobel Prize in Physics. Central enigmas of this field are the origin and sources of what is called ‘dark energy’ and ‘dark matter’, the latter being estimated to constitute about 96% of the universe.¹²⁸

SLAC’s move into astrogravity program included, first, the Unconventional Stellar Aspect experiment as part of the Air Force’s ARGOS satellite mission, and second, collaborative engineering with Stanford’s physics department to build gravitational wave interferometers.¹²⁹ In the late 1990s, SLAC announced a move into space research by collaborating in a consortium that built the Gamma-ray Large Area Space Telescope (GLAST), a move that was supported by the Science Policy Committee.¹³⁰ The growth of astroparticle physics and cosmology also involved a migration of a significant number of SLAC physicists from accelerator-based HEP to GLAST and other projects.¹³¹

In the early 2000s, the laboratory’s shift into astroparticle physics and cosmology was deepened when SLAC and Stanford University, following donations from the Kavli Foundation and two individuals (Pehong and Adele Chen), established the Kavli Institute for Particle Astrophysics and Cosmology, or KIPAC.¹³² Three years later, KIPAC opened its 25,000 square-foot headquarters building at the SLAC campus with workspace for 90 people, ‘a handsome, big-windowed structure that overlooks rolling green hills. It contains an auditorium big enough to host a fair-sized international scientific conference.’¹³³

The institute continued fostering the collaboration between Stanford faculty and SLAC.¹³⁴ Examples of this collaboration were Roger Blandford and Steven Kahn, the new KIPAC Director and his deputy, who held joint appointments with Stanford’s physics department and SLAC. In the mid-2000s, SLAC had two faculties: 35 faculty members in the particle and astroparticle physics division, 31 of whom held tenure-line positions; and 20 faculty members in the photon science division, 12 of whom held tenure-line positions. Of the

43 faculty members with tenure-line positions, 16 held joint appointments with Stanford departments.¹³⁵ In the following years, KIPAC was frequently cited for the successful transfer of accelerator-based scientific and technical skills to non-accelerator-based astrophysical and cosmological questions and methods.¹³⁶ Therefore, it is fair to say that KIPAC opened an important new avenue for SLAC's gradual process of renewal.

However, while SLAC's shift towards non-accelerator-based astroparticle physics and cosmology unfolded in the context of growing resources and new scientific opportunities, the process of gradually abandoning accelerator-based HEP, which occurred almost in parallel, involved many disappointments and frustrations. First, the cancellation of the SSC in 1993 forcefully reminded the international HEP community that it would be unrealistic to expect an ever-growing research field with increasingly bigger and more powerful machines (Section 2). Second, the federal appropriations for SLAC's HEP research program had sharply decreased since the 1990s (Section 3). Yet, high-energy physicists continued their efforts towards what was called the 'Next Linear Collider' (NLC), and later the 'International Linear Collider' (ILC). The HEP program still had many supporters at SLAC, including three Nobel laureates (Burton Richter, Richard Taylor, Martin Perl). Although it was relatively clear from the beginning that, given its physical extensions, the NLC/ILC could not be built in Menlo Park, the SLAC leadership was actively involved in its planning. At about the same time, the DOE's High-Energy Physics Advisory Panel urged the federal government 'to start thinking of new machines, in particular a 20-mile long "Next Linear Collider", with the United States in a leading role'.¹³⁷

SLAC was not the only laboratory where such plans for the next positron electron linear collider were made. At the DESY in Hamburg, Germany, plans for a TeV Energy Superconducting Linear Accelerator (TESLA) were announced in 1991, and the design report for the TESLA Test Facility had been finished in 1995.¹³⁸ Although DESY did not operate a linear accelerator like SLAC, it was in a similar situation because its hadron-electron collider HERA would be shut down by the end of the 2000s, as would PEP-II, SLAC's flagship machine. Apparently, the leaders of DESY and SLAC did not pull on one string at that time, prompting SLAC's Science Policy Committee to issue a warning: 'While it is not clear what the ultimate resolution of this situation will be, many members of the international community regard it as extremely unlikely that two linear colliders will be built in the world'.¹³⁹ Dorfan continued these efforts, and the NLC/ILC was discussed extensively in each of SLAC's annual and mid-term research plan documents.¹⁴⁰

In 2004, Dorfan wrote a memo about the 'Future of SLAC' that illustrates the frustrations on the side of high-energy physicists in the mid-2000s, both at SLAC and elsewhere, as it became more and more evident that the NLC/ILC was not going to be built anywhere soon. The memo emphasises SLAC's deep commitment to being involved in building the next HEP accelerator: 'The primary focus of the laboratory's future accelerator-based particle physics program is the linear collider. The linear collider is the highest priority new facility for the field of high-energy physics'.¹⁴¹ The memo also argues that although a 'no linear collider scenario' would 'not threaten the future of the laboratory' because SLAC had diversified its research program and would 'thrive even in the absence of the linear collider', such a scenario 'would threaten the survival of a healthy US high-energy physics program'.¹⁴²

In March 2007, Dorfan announced that he would retire from his position in the fall of the same year.¹⁴³ In September 2007, Stanford President Hennessy appointed Persis Drell acting director, and three months later, she was appointed SLAC director.¹⁴⁴ Before joining

SLAC in 2002, Drell had been at Cornell University. At SLAC, she worked in the astroparticle physics program where she was deputy project manager in the construction of the GLAST, later renamed Fermi Gamma-ray Space Telescope. In 2005, she became associate director and head of the Particle and Astroparticle Division.¹⁴⁵ Therefore, Drell was recruited from one of SLAC's new strategic research areas: non-accelerator-based astroparticle physics. Interestingly, Persis Drell's father Sidney Drell had been deputy director at SLAC between 1971 and 1997, first under Wolfgang Panofsky and later under Burton Richter.¹⁴⁶

In the first annual laboratory plan, overseen by Persis Drell, and in contrast to earlier planning documents, SLAC's continued involvement in the NLC/ILC planning was called into question.¹⁴⁷ Furthermore, the report argues that when 'facing hard choices as to what to maintain in that scenario', priority would be given to astroparticle physics projects, such as the Large Synoptic Survey Telescope.¹⁴⁸ In the following years, the fact that the DOE's BES budget would grow at the expense of the HEP budget was increasingly framed as normality and not so much as crisis.¹⁴⁹ Likewise, in 2012, Drell announced: 'the Office of Science saw a 0.9% increase, with the Office of BES (which funds the LCLS and SSRL) increasing by 1% and High-Energy Physics decreasing by 0.5%'.¹⁵⁰

Although the gradual decrease of the accelerator-based HEP program had become a normality during the 2000s, a major crisis occurred in 2008 when the DOE announced a substantial budget cut of about \$30 million in its HEP program. The fact that PEP-II would close by the end of September 2008 had been written into the budget several years earlier, and SLAC had already started a procedure that would reduce its HEP staff by 200 by the end of September 2008. About 120 of these 200 people were laid off voluntarily and about 80 involuntarily. When the news arrived that PEP-II would be shut down six months earlier than planned, an additional 125 people had to be laid off involuntarily. Initially, Drell was heavily criticised for implementing what many believed was an inappropriate decision by the DOE. Nobel laureate Martin Perl even demanded that Drell oppose the decision and offer her resignation if these budget cuts were to be pushed through.¹⁵¹ Yet, 'Drell simply made the cuts'.¹⁵² Over time, however, it became evident that the budget crisis had only accelerated a process that was unfolding anyway, which was the main reason Drell supported the DOE's decision.¹⁵³ Even former critics, including Martin Perl, realised that, 'what Drell did was best for SLAC'.¹⁵⁴

As if the early cancellation of PEP-II had not been enough, in the summer of 2008, the DOE initiated a discussion about a new name for SLAC. According to the *San Francisco Chronicle*, the DOE's Office of Science argued that the new name should 'reflect changes in the direction of research since the facility opened 46 years ago' and that 'the federal agency has renamed many of its 16 other national laboratories to reflect their new research directions'.¹⁵⁵ Particle physicists were reported to be very concerned and bewildered. Yet, following extensive discussions both at SLAC and Stanford, the DOE agreed, in October 2008, to 'SLAC National Accelerator Laboratory'.

6. Finishing the transformation: new safety culture and management structure

Three key elements of SLAC's transformation have been discussed so far: since the 1990s, the integration of an extended synchrotron radiation research program in the laboratory's mission and strategy (Section 3); and since the 2000s, both the design and construction

of a linear-accelerator-based photon science machine (Section 4) and the shift towards non-accelerator-based astroparticle physics and cosmology (Section 5). Yet, the transformation of SLAC went deeper: this section analyses how significant performance failures in safety and management led to an organisational crisis that gave rise to both a new safety culture and a new management structure. Thus, by the early 2010s, SLAC's transformation process was completed.

SLAC's safety and management crisis had been looming, but in October 2004, it broke out when a major and nearly fatal accident occurred: a subcontractor electrician 'received serious burn injuries requiring hospitalization due to an electrical arc flash that occurred during the installation of a circuit breaker in an energized 480-Volt electrical panel'.¹⁵⁶ The gravity of the accident led to an investigation by the DOE that found that the accident 'resulted from deficiencies in SLAC's work control planning and implementation processes' that 'violated all of the Integrated Safety Management guiding principles and core functions'. Therefore, the investigation concluded 'that this accident was preventable'.¹⁵⁷

The investigation report voiced considerable criticism about SLAC's safety culture more generally. It found 'that unsafe conditions and operations have become an accepted part of the everyday way of doing business' and 'that rigorous safety oversight (...) is frowned upon and given very low priority'.¹⁵⁸ As an example, the report cited an electrical safety review at SLAC that found 23 out of 31 electrical hot work permits between February and May 2004 had been granted without necessary justification for work to be conducted while the systems were energised, but that SLAC management 'did not demonstrate a sense of urgency in implementing the recommendations that resulted from the review'.¹⁵⁹

SLAC has had a record of performance failures in safety, environment and health. In 1991, the DOE initiated a process of in-depth reviews at all of its laboratories, the so-called 'Tiger Teams' reviews, which scrutinised every laboratory for infractions and imposed penalties for violations.¹⁶⁰ At that time, the *Palo Alto Weekly* published an article claiming that 'SLAC has apparently concentrated so heavily on its mission (...) that it did not follow basic federal, state, and local regulations to protect workers and the community from harm'.¹⁶¹

In response to the 'Tiger Team' findings and concerns, SLAC prepared a corrective action plan but made its implementation contingent on the availability of resources.¹⁶² Then, several years later, SLAC's Science Policy Committee voiced concerns about the safety culture at SLAC, in particular that 'some of the staff feel pressure from their science colleagues to give machine operation priority over safety', suggesting that the corrective action plan had not yet been fully implemented. In fact, SLAC acknowledged that 'sufficient capital funding has not been available to fully renovate the utility systems'.¹⁶³ SLAC's leadership responded to the budget cuts in the 1990s predominantly by reductions in the laboratory's technical staff.

Following the 2004 accident, SLAC Director Dorfman took several measures. He merged the Experimental Facilities Department and the Site, Engineering and Maintenance Department, established a new Operations Division;¹⁶⁴ started to hold annual safety and security briefings; and created new administrative leadership positions both to improve the laboratory's internal information flow and to better comply with regulatory and contractual standards.¹⁶⁵ Yet, despite these efforts, in 2006 and 2007, SLAC received in the environment, safety and health appraisal process safety grades below what the DOE defined as meeting its expectations. Finally, Dorfman hired McCallum-Turner, an external consultant firm with many years of experience with national laboratories funded by the DOE, to improve SLAC's overall management and operations.¹⁶⁶ McCallum-Turner identified several management

and organisation areas that needed increased attention by SLAC, including integrated performance management, requirements management, quality, human resources, information technology, environment, safety and health, facilities management, and work planning and control.¹⁶⁷

There are several possible reasons why SLAC continued to have performance failures in safety, environment and health after the arc flash accident in 2004. First, while 'SLAC's scientific mission and the majority of funding had shifted from high-energy physics to basic energy sciences, (...) many of the core capabilities of the staff and the organizational culture of the laboratory had not yet been aligned to support a BES-led laboratory, creating a lack of clarity with regard to SLAC's future direction'.¹⁶⁸ This line of argument is supported by William Madia, the former director of Oak Ridge National Laboratory, and later vice president for SLAC at Stanford University, arguing that SLAC's main challenge was 'to refocus accelerator scientists on photon science and transform a laboratory from an organization wherein two-thirds of the employees served the mission of HEP, and one-third of the employees served the mission of BES, to the reverse'.¹⁶⁹

Second, the relationship between SLAC and the DOE was strained.¹⁷⁰ Ever since the 'Tiger Teams' had criticised its internal environment, safety and health operations, the DOE's oversight was regarded by SLAC managers as bureaucratic and of little value in terms of accomplishing the laboratory's research mission. Yet, Madia argues that 'SLAC was unusual in the national laboratory system in that they rarely attended peer meetings. (...) The laboratory completely ignored what DOE was saying and defended the operations at SLAC as being not so bad'.¹⁷¹

Third, the relationship between Stanford University and the DOE had been under stress, a situation that emerged from negotiations for a new SLAC contract. Back in 1995, the DOE proposed to end the 'no gain – no loss' principle under which Stanford had been operating SLAC and instead pay Stanford a fee but shift the liabilities occurring from operating SLAC to Stanford. Gerhard Casper, Stanford's president and a trained lawyer himself, did not agree to this change.¹⁷² When Stanford finally signed the new contract in 1998, it did not collect the fee because that was regarded as disadvantageous in the case of litigation. The negotiations, however, had a detrimental effect on the relationship between Stanford and the DOE in that the latter 'was not viewed as an enlightened ministry that would do the right things. It was instead viewed (...) with a lot of distrust'.¹⁷³

Finally, Stanford University was perceived by many SLAC employees as the 'absentee landlord'.¹⁷⁴ The university received and positively acknowledged the Science Policy Committee reports twice a year but did not meddle in SLAC's internal administrative issues at all: 'I did not see Stanford University intervening in a way that I would have, had I been University Officer, given the fact that the university was the operator of SLAC'.¹⁷⁵ Although the director of SLAC would meet on a regular basis with the Stanford provost and the Stanford president, 'it was a very hands-off approach' and 'Stanford did not realize its role to do an in-depth review'.¹⁷⁶ When after the arc flash accident, the DOE urged Stanford University to assume its formal role as contractor, it turned out that 'Stanford did things administratively very differently' and on both sides 'it was not really well understood what the rules and responsibilities were'.¹⁷⁷

From the very beginning of her tenure, Drell redefined the role of the SLAC director towards the two faculties. While previous SLAC directors had participated in all meetings of the particle and astroparticle physics faculty, they had not engaged in the same way with

the photon science faculty. Drell's approach was different; she 'set up three joint faculty meetings a year to meet with both faculties together and inform them about what was going on'.¹⁷⁸ Most important, she did not join by default the faculty meetings of the particle and astroparticle physics faculty anymore, although it was her home faculty, but only on request and when particular issues had to be discussed. In this way, she made impartiality and mutual respect for both faculties a core principle of her leadership. The redefinition of the SLAC director's role was part of Drell's 'One Lab' concept. Instead of widening the rift between the declining HEP program and the ascending BES program, Drell argued that SLAC needed 'an organization that optimally supports our broader mission'.¹⁷⁹ She argued that accomplishing this broader mission required the support of those people who built and maintained the accelerators and who could serve photon science as readily as they had served HEP for many years.¹⁸⁰

Drell reorganised SLAC's organisation and management structure in her first month in office, at a time when she was still acting director (Figure 5). Administratively, she split up the existing Operations Directorate into a new and smaller Operations Directorate and a new Engineering and Technical Support Directorate. The latter would later become the Accelerator Directorate. On the science and technology level, she upgraded SSRL, which had been a department in the Photon Science Directorate, into a full-fledged directorate. Furthermore, she restructured the LCLS Directorate internally and thus created three new departments there. At the executive level, she established a Director's Council, in which

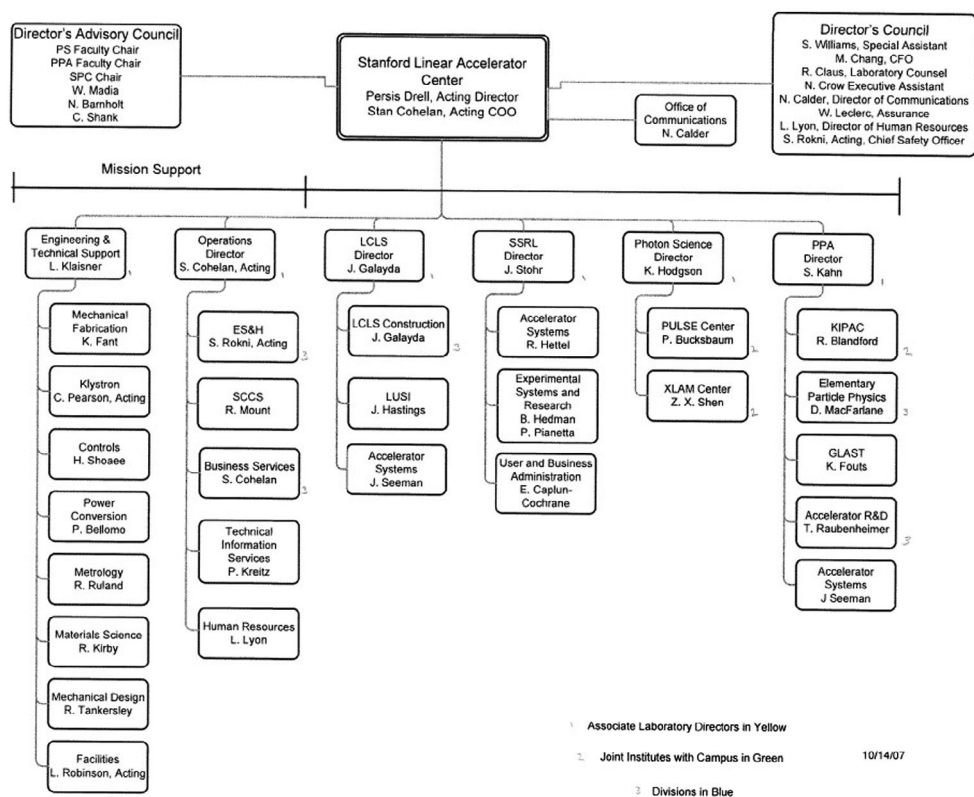


Figure 5. Organisational Chart of SLAC, 2007; Source: SLAC National Accelerator Center.

all chief officers and executive assistants were represented, and ‘there weren’t any decisions made at SLAC at the high level that weren’t approved by that council’.¹⁸¹ This new council would later become the Director’s Assurance Council. Drell also created the Director’s Advisory Council, in which the chairs of the two SLAC faculties and the Science Policy Committee and other advisors were represented, including William Madia, Stanford’s vice president for SLAC since January 2008. Madia provided valuable advice for Drell, based on his long tenure in the US national laboratory system. The vice president position was created to improve information flow, coordination and cooperation among Stanford, SLAC and the DOE.¹⁸²

In addition to making changes to the laboratory’s management structure, Drell hired new staff from outside: ‘I am not proud of this figure but it is a fact that between when I started and when I left, 43% of the laboratory staff were new’.¹⁸³ Recruiting outside people was required, according to Drell, to make the double transition, first from HEP to both photon science and astroparticle physics and cosmology, and second, from a laboratory without a strong safety culture to one where such a culture thrived. More specifically, this meant replacing almost every operational function, including the head of information technology, the head of human relations, the chief financial officer, and the chief safety officer.¹⁸⁴

The following years witnessed noteworthy performance improvements. Since 2008, the DOE’s Laboratory Performance Report Cards in both environment, safety, and health, and in facilities management have improved to a level that is in line with the DOE’s expectations.¹⁸⁵ At the same time, the relationships among SLAC, Stanford University and the DOE were revitalised, and mutual trust was built up. With the vice president for SLAC, Stanford had a more formalised and professional relationship with SLAC, and there was a functioning three-way partnership among the DOE site office, Stanford and SLAC.¹⁸⁶

In November 2011, when Drell announced that she would step down from her position as SLAC director, she concluded:

We are a different laboratory than we were four years ago, with tremendous momentum going forward (...). Our infrastructure is being rebuilt with many major new buildings and renovations of old ones. We have outstanding new staff and new leadership in many areas of the laboratory.¹⁸⁷

About one year later, in October 2012, Chi-Chang Kao, the Associate Laboratory Director for SSRL (and acting Associate Laboratory Director for Photon Science), accepted the position of SLAC Director.¹⁸⁸ Fifty years after SLAC had been founded, a photon scientist became its director.

7. Conclusion

This article examines the most recent history of SLAC’s gradual transformation from a national laboratory once founded as a facility for accelerator-based particle physics to a situation in which its main experimental program comprises multi-disciplinary photon science and particle astrophysics and cosmology. Today, SLAC operates two photon science machines (SPEAR 3 and LCLS) but no particle physics machine, and another photon science machine, the LCLS-II, is currently being built. Characterising the overall transformation as a gradually unfolding process includes years in which changes in the laboratory occurred more rapidly and, thus, were perceived more as a crisis than as a smooth transition. As

explained above, the premature shut-down of PEP-II in 2008 is a relevant example. However, although this crisis accelerated the speed of change, it did not put SLAC on a different path.

As the article shows, SLAC's transformation was made possible both by its dismantling of accelerator-based particle physics program, including the shut-down of particle accelerators (PEP-II), and by reducing its particle physics workforce, and at the same time, by redeploying scientific and technical capabilities from that program for new photon science machines as experimental user facilities for the materials and life sciences. The migration of particle physicists and accelerator scientists, employed at SLAC, into the new research program and the conversion and extension of former particle physics machines for photon science (SPEAR, LINAC) helped redeploy these scientific and technical capabilities, but the eventual shift towards the new research program also involved (and necessitated) considerable recruitment of scientists from outside and the building of entirely new experimental infrastructures (LCLS, LCLS-II).

The redeployment of SLAC's core capabilities in accelerator science, detector development and large data management for photon science allowed the laboratory to make its transformation. In other words: SLAC heavily drew upon what it was really good at, and repositioned itself to find a new application – the LCLS. Therefore, a particularly important element of the SLAC's transformation was the building of the LCLS because in the context of the preparation and construction of this FEL, a coalition emerged between particle and accelerator physicists on the one hand and photon scientists on the other hand. This coalition helped overcome resistance among synchrotron radiation researchers at SLAC, Stanford University and elsewhere who initially were sceptical that the new light source would work. This coalition convinced other photon scientists to join and provide support for the realisation of new scientific and technical opportunities associated with the LCLS. Their efforts were crucial in the ongoing redeployment of scientific and technical capabilities from experimental particle physics for photon science.

Furthermore, SLAC's transformation unfolded in a generally supportive and entrepreneurial academic environment in which collaboration between Stanford faculty and photon science faculty at SLAC was widely practised. This collaboration was situated in a funding context characterised by growth, and it involved several institutional entrepreneurs who were not only scientific pioneers but also experienced in mobilising support from funders. Therefore, the upgrade of SLAC's former HEP machine SPEAR, the design and construction of the LCLS, and the move into the field of astroparticle physics and cosmology are all examples of how a funding context characterised by growth, institutional entrepreneurs striving for the realisation of new scientific opportunities, and the supportive academic environment of Stanford University contributed to SLAC's transformation.

Yet, this article also illustrates that budgetary constraints associated with the gradual dismantling of experimental HEP at SLAC resulted in continuous under-investments in safety infrastructure that culminated in severe safety failures, including a major accident. These factors created a situation that threatened the survival of the entire laboratory. SLAC leadership managed both to establish a new safety culture and to accommodate the laboratory's organisational structure to its changed mission and research programs. Thus, the transformation of SLAC showcases that adapting to a changing funding environment, particularly with regard to the gradual dismantling of experimental HEP, involves organisational risks that can potentially jeopardise the otherwise successful steering into new and promising research fields.

In comparison with other National Laboratories, most of which had a considerable breadth of scientific activities, SLAC's origin as a single-mission particle physics laboratory, with photon science added as a second mission in 1992, makes its transformation particularly profound. Compared to Argonne, Berkeley and Brookhaven, where to some extent scientists could migrate to existing programs and new initiatives could be built up by 'recombinations' of assets already part of the lab organisations, SLAC had to reinvent itself largely by developing entirely new strategies and projects.¹⁸⁹ As the example of the LCLS shows: while breaking new ground scientifically and technically, the LCLS project drew on existing physical infrastructure and human resources. SLAC's move into astrophysics and cosmology made use of existing assets, but was also an entirely new activity built up by SLAC's leadership and staff in collaboration with Stanford University.

The transformation examined in this paper is part of a larger current of change in science and technology in the late twentieth century and onwards. This change complemented the dominance of nuclear and particle physics in national and international science budgets with a rise of life sciences and materials sciences, with applications of similarly tremendous impact. Photon science took a lead position on the side of experimentation in these growing fields of research and development and became a new form of Big Science, generously funded by governments and with user communities expanding across academia as well as industry.¹⁹⁰

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4. Kevles, "Big Science"; Johnson, "End of pure science".
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9. NSB, *Science and Engineering Indicators 2004*, Appendix Table 04–28.
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11. Greenberg, *Science, Money and Politics*, 405.
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13. Hoddeson et al., *Fermilab*, 340.
14. See note 9.
15. Neal et al., *Beyond Sputnik*, 82.
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20. See note 18.
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37. *Ibid.*, 8–9.
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44. SSRL, "SSRL Division Questionnaire", 2.
45. SLAC, "Institutional Plan 1993–1998", 16–32.
46. SSRL, "SSRL Division Questionnaire", 4.
47. SLAC, "Institutional Plan 1996–2001", 12.
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49. SSRL, "SSRL Division Questionnaire", 3.
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63. Lehman, "Close-out Report", 3.
64. *Ibid.*, 6. The review panel was chaired by Sam Krinsky (Brookhaven National Laboratory).
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67. Lehman, "Close-out Report", 39–41; email from Patricia Dehmer to first author, 6 June 2017.
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70. *Ibid.*, 5.

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72. SLAC, "Annual Laboratory Plan 2013", 7. The decline in number users at SSRL may have been caused by other factors as well, most notably the competition for users at the other light sources in the U.S.
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81. Hallonsten, *Big Science Transformed*, 125–37.
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as part of the increased oversight and push for accountability at the US national laboratories starting in the 1980s. With Lehman's retirement in December 2013, the name 'Lehman Review' has given way to 'OPA Review', i.e. the reviews no longer are named for the head of the Office of Project Assessment; email from Patricia Dehmer to first author, 6 June 2017.

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