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From particle physics to photon science: Multi-dimensional and multi-level renewal at DESY and SLAC

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Studies of institutional transformation in science have largely overlooked Big Science installations, despite far-reaching changes to the roles and functions of such large labs in the past decades. Here, we present and analyze two Big Science labs that have undergone profound transformations from single-purpose particle physics labs to multi-purpose centers for so-called photon science: SLAC in the USA and DESY in Germany. We provide brief historic accounts of the labs and an analysis of the processes of change on different levels and from different aspects informed by a theoretical framework of institutional change in science. Thus, we describe the relevance of the study of Big Science labs from the perspective of institutional change and in terms of science policy/management. We also prove the aptness of the framework used and pave the way for a detailed analysis of particular forces of change and their interrelatedness.

Keywords: institutional renewal; DESY; SLAC; Big Science; particle physics; photon science.

1. Introduction

Analyses of institutional or intellectual change in the global research system have typically focused on the academic and private sectors, which leaves out a great proportion of national R&D systems, namely systems of national laboratories (SNLs). These systems, despite consuming in some cases a considerable share of a nation's public expenditure on R&D, have largely been overlooked in the study of change in science.

Traditionally, SNLs are defined by their hosting of large-scale scientific and technological installations and projects, also known as Big Science. Science historians have studied Big Science extensively (Blaauw 1991; Crease 1999; Hermann et al. 1987, 1990; Hoddeson 1983; Hoddeson et al. 2008; Holl 1997; Krige 1996; Lohrmann and Söding 2009; Ritter 1992; Seidel 1983; Westfall 1989, 2008b, 2010, 2012; Westwick 2003), but sociological studies of Big Science are just beginning to emerge. In particular, the role of SNLs in quantitative and qualitative changes to science policy systems in the last decades of the 20th century in institutional change and renewal in science remains unknown. Therefore, we argue that attention needs to be paid to Big Science and SNLs in terms of change and the capability for institutional and organizational renewal and adaptation, and that such studies would yield important insights for the field as a whole, and specifically for science policy and management. Despite their original association with the specific 'technoscientific regime' of the Cold War, SNLs are remarkably resilient and appear to have adapted to the radically different post-Cold War social and economic context without major closures, instead lab operations have continued, partly for new purposes (Hallonsten and Heinze 2012; Elzinga 2012; Westfall 2012). This insight, in particular, calls for deeper analysis of the mechanisms underlying institutional renewal in Big Science and SNLs.

Here, we report the first results of in-depth case studies of two large, public R&D centers in the USA and Germany, respectively, the SLAC National Accelerator Laboratory (SLAC) and the Deutsches Elektronen-Synchrotron (DESY). The cases have been chosen on the basis of our aim to compare the capability of institutional and organizational adaptation in the two countries, and on the basis that the two labs have been profoundly transformed in terms of scientific activities and have renewed their organizations in order to facilitate scientific change. We analyzed the cases within a recently developed theoretical framework for processes of institutional renewal (Heinze and Münch 2012), which was previously applied to the systemic level of SNLs in Germany and the USA (Hallonsten and Heinze 2012). This framework emphasizes that institutional renewal is typically not caused by radical exogenous shocks, but rather by incremental endogenous rearrangements that adapt institutions to altered social, political, and economic conditions. The framework specifically facilitates the identification of change processes through the layering of new arrangements on top of existing structures—replacing these structures with new research capacities and infusing a new purpose or mission into existing units and positions, thus converting them—or by entirely dismantling the existing research infrastructure or organizational units.

Importantly, though one of the chief purposes of these studies was to make systematic comparisons between the research systems of Germany and the USA, the comparative perspective will not be discussed in this paper, as it demands yet another level of detail and those studies are ongoing. The present paper will limit itself to a discussion of the processes of institutional renewal in the two cases, and the use of both of the case studies in this analysis is primarily a means of highlighting their comparability and showing that the gradual transformation of a lab from particle physics (PP) to synchrotron radiation (SR)/photon science (PS) is not a singularity, as it is found in two different national contexts. The present paper analyzes the gradual transformation of the two labs with the aid of the theoretical framework in a fashion that allows for a flexible interpretation of processes of institutional renewal on the level of organizational structure, research infrastructure, and scientific fields. By exposing the complexity of the processes of change at these labs, this paper assesses the value of a theoretical approach and takes an important step in the detailed analysis of these two SNLs. Specifically, this paper contributes to the field of science policy/management studies by showing that the long-term renewal of the two labs in question occurred via parallel and interconnected changes on three levels, which roughly correspond to the realms of lab management and leadership, national policymaking processes, and the cognitive/intellectual evolution of the sciences concerned.

First, we explain the context of this paper and the study of which it is a part. Next, we present brief histories of the two labs and a theoretical framework for processes of institutional renewal as developed in previous papers. We then use this framework to analyze the histories of the two labs.

2. Context

The two labs under study, DESY and SLAC, are part of the German and US SNLs, respectively, and situated in similar, but specific, institutional contexts. The US system of national laboratories (USNLs) and the German Helmholz-Gemeinschaft (HGF) were both products of the systematic buildup of federal research efforts in nuclear physics in the aftermath of World War II. Since that time, the rationale for spending vast sums of government (federal) money on research installations for Big Science has changed several times, with an overall move away from issues of national security/prestige and Cold War logic towards health, sustainability, and competitiveness in a globalized knowledge economy (Hohn and Schimank 1990; Ritter 1992; Hallonsten and Heinze 2012; Westfall 2008a). Yet, the lab systems are intact, and no USNL or HGF lab has been shut down. Both systems have undergone phases of initiation, expansion and diversification, and consolidation that roughly correspond to the cycles of macro science policy in the two countries and the (Western) world at large (Hallonsten and Heinze 2012).

The USNLs and HGF differ somewhat with respect to legal status, funding procedures, and organizational arrangements, but both are comparably privileged parts of their respective country's public R&D system. Interestingly, though the overall federal expenditure of the two systems has significantly fluctuated over the decades, the systems have not expanded or contracted accordingly. The real budget declines in the 1970s and 1990s in the USA, and in the 1990s in Germany, have not caused the shutdown of any labs. Similarly, the periods of budget increase in the 1980s in the USA and the early 2000s in Germany did not lead to any significant expansion of the systems, only the founding of a few new labs (Hallonsten and Heinze 2012).

However, the missions and activities of the labs in the two systems have changed profoundly, though mostly gradually, over the years due to scientific developments and not least of all to changes in social, political, economic, and military embedment (Hallonsten and Heinze 2012; Westfall 2008a; Stevens 2003). Both systems were established in the immediate post-World War II period and were, in a sense, embodiments of the typical science and technology optimism of that era, and more specifically the beliefs in (and fear for) the powers of nuclear energy. Government funding of (nuclear) physics research was very generous in the immediate aftermath of the war, and it received another boost due to the 1957 so-called 'Sputnik shock' in the USA and Western

Europe, which led to intensified efforts in government-funded military and civilian R&D, especially in the realm of nuclear research (Gaddis 2005: 66–7). Both DESY and SLAC were established in the period immediately after the 'Sputnik shock'. The generosity in funding for Big Science installations in the 1950s and early 1960s came to an end with the political and economic developments in the 1960s and 1970s, which also coincided with increasing social unrest and heavy questioning of the 'military–industrial complex' and government policy agendas, including science and technology policy, as well as Cold War *détente* (Westwick 2003: 296; Gaddis 2005: 199–200). In combination with the economic downturn in the 1970s, these developments resulted in increased pressure for deliverables from science in general. The momentous re-intensification of the Cold War in the 1980s and the consequential increase in R&D spending in both Western Germany and the USA, which was also reflected in the growth of USNL and HGF budgets (Hallonsten and Heinze 2012: 453), could not prevent the reinvigoration of the trend for increased demands from society, which also led to the introduction of technology transfer as an explicit mission for SNLs in the late 1980s and 1990s. Simultaneously, scientific developments from within and without the labs created new niches such as: energy and climate, information technology, and materials and life sciences. In a process of gradual adaptation to all of these new circumstances, in the 1970s several labs began to explore the use of large accelerator and reactor facilities (Hallonsten and Heinze 2012; Westfall 2008a,b, 2012; Hallonsten 2012). The end of the Cold War, the cancellation of the Superconducting Super Collider (in 1993), and the rise of the life sciences and nanotechnology/nanoscience in the 1990s completed the system-wide transformation. Nuclear and PP was no longer the star of every show in the SNLs, but stood back in favor of materials and life sciences-oriented Big Science.

This general development is exemplified in the two labs studied here. Both of the labs were founded (DESY in 1959, SLAC in 1961) as single-purpose and single-mission research centers for PP and given the task of running their respective nation's state-of-the-art accelerators for this purpose (Riordan 1987: 16; Habfast 1989: 2–3). At both labs, auxiliary utilization of the accelerators for the production of X-rays for the study of materials (SR) was soon incorporated into the research portfolio. Due to the mentioned changes in the surroundings, the status and *raison d'être* for PP gradually dwindled in the 1970s, 1980s, and 1990s, and materials science concurrently increased its popularity and share of national physics/science budgets and extended its use of X-rays produced by large accelerators. In addition, various uses for these high-quality X-rays within the life sciences added to the growing demand for specialized accelerator facilities for SR. In the course of 30–40 years, SLAC and DESY underwent gradual alterations to their portfolio of scientific activities in a manner consistent with these changes, and essentially underwent a complete transformation from PP centers to labs supporting materials science and life science. Today, SLAC and DESY run some of the world's most advanced SR facilities and are in the process of building cutting edge facilities for the future, though their last experimental PP programs have been terminated (Hallonsten 2009: 112–53; Lohrmann and Söding 2009: 233–64).

Our previous analysis showed that, at the systemic level, the capability to adapt to changing conditions in the environment has played a role in keeping the SNLs of Germany and the USA intact in terms of the number of labs in operation. Most importantly, though change has sometimes been radical (for instance, the end of the Cold War), the SNLs have evolved along gradual paths of institutional change rather than through discontinuous events (Hallonsten and Heinze 2012). The present paper is the first step towards a detailed case study-based analysis of this gradual institutional change, and the cases have been chosen specifically for this purpose.

3. A brief history of SLAC

The SLAC National Accelerator Laboratory[1] is located a few kilometers west of the main Stanford University Campus, south of San Francisco, California. The laboratory is a dual-mission US National Laboratory for PP/particle astrophysics and PS. SLAC operates two main user facilities for PS, the Stanford Synchrotron Radiation Lightsource (SSRL) and a free-electron laser, the linac coherent light source (LCLS). The Kavli Institute for particle astrophysics and the PP division (working primarily with US experiments at CERN) constitute the other part of the lab.

The origin of SLAC dates back to the 1930s and advances in particle accelerator construction at the Stanford University physics department. The post-World War II flood of money from the federal government to (sub)nuclear physics fueled the development of a lively accelerator development program, and in the late 1950s a proposal was submitted to the Atomic Energy Commission (AEC) to build a 3-km linear accelerator (linac) adjacent to the Stanford campus, at a cost of over US$100 million. Stanford physics professors Wolfgang Panofsky and Robert Hofstadter were behind this idea to give Stanford physicists access to:

> ... a frontier of physics unapproachable by any other means now considered feasible. (Galison et al. 1992: 65)

PP was a major part of the federal R&D efforts and:

> SLAC was just another machine in a long line of federally funded accelerators. (Wang 1995: 332)

Consequently, on 15 September 1961, the US Congress funded the project with $114 million. In May 1966, the

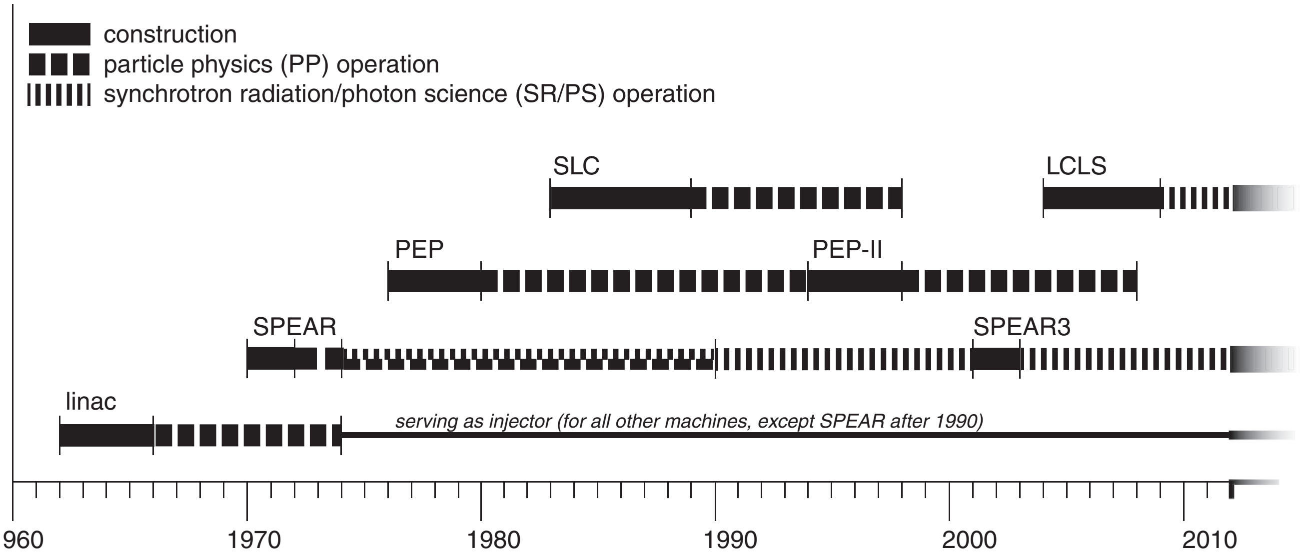

Figure 1. Timeline of major accelerator facilities at SLAC (adapted from Hallonsten 2009).

SLAC machine started operation (Wang 1995: 352–3). Organizationally, SLAC became a newly founded national lab but was still a part of Stanford University, a compromise solution that, in principle, made SLAC open to users from all over the country, but in practice gave Stanford faculty priority access (Lowen 1997: 179–86; Hoddeson et al. 2008: 45).

The linac was, by most accounts, a highly productive physics machine in the approximately eight years it ran as a separate machine (see Fig. 1) (Westfall 2002: 387; Martin and Irvine 1984: 200), but cycles of accelerator construction and operation were short and the SLAC management had already started planning a second machine before the linac was even in operation. The Stanford positron–electron accelerator ring (SPEAR) storage ring was built to increase the rate of interaction between particles smashed together, and it was constructed in the years 1970–2 (Panofsky 2007: 119; Richter 1997: 275). Built and operated by Stanford physicist Burton Richter's team, the SPEAR was a key player in the 1974 'November Revolution' in PP that led to the establishment of the so-called standard model and secured Richter the Nobel Prize in Physics in 1976 (Brown et al. 1997: 5).

However, the construction of a storage ring at the SLAC campus also attracted the interest of Stanford condensed matter physicists William Spicer and Sebastian Doniach, whose interests in the emerging use of accelerators for the production of extremely bright X-rays (SR) for various studies of materials had made them curious about the prospects of using SPEAR for such work. The potential had been proven at various locations in Europe and the USA throughout the 1960s (Hallonsten 2009: 112; Crease 2008: 439–41). After thorough assessment of the risks and benefits, the Stanford Synchrotron Radiation Project (SSRP) was allowed to act as an outside users group at SLAC and to utilize the X-rays produced by SPEAR. With the aid of a grant from the National Science Foundation (NSF), the project got underway with spectroscopy experiments that had the 'highest resolution yet seen' (Cantwell 1994b: 5; Hallonsten 2009: 116).

The NSF had already made plans to support a national effort in SR, and the gradual expansion of SSRP from trial project to nationwide user facility suited their ambitions well. In 1974, the lab opened to outside users and, as results emerged, the NSF-funded expansion proceeded (Doniach et al. 1997). Compared to other SR ventures around the world, the X-rays produced by SPEAR were considered a 'unique' feature: most other labs used less advanced accelerators that restricted them to the use of ultraviolet radiation (Robinson 1975: 1074). Publications showed increases in resolution of factors of several tens of thousands compared to state-of-the-art laboratory benchtop X-ray sources (Hallonsten 2009: 118). Unfortunately for the SSRP, the 1974 'November Revolution' caused SLAC particle physicists to want to operate SPEAR in a mode that did not allow for the production of X-rays, and so less than a year into its operation as a user facility, SSRP lost much of its appeal. The reason was technical, but also institutional: SLAC was a single-purpose PP lab and the SSRP were only guests (or 'parasites', as they normally called themselves) with no real say in matters of priority regarding technical performance (Doniach et al. 1997: 382; Hallonsten 2009: 120–1). The solution to this 'X-ray drought' came several years later with a technical innovation called the wiggler, which allowed X-ray production from SPEAR at lower energies and caused no harm to the PP program. The first wiggler was inserted in 1978 (Hallonsten 2009: 122). It paved the way for significant improvements in performance for global SR research using the wigglers and their siblings, undulators, which are now standard equipment at SR laboratories worldwide.

The scientific success in PP using the SPEAR soon led to plans to build yet another, significantly larger, storage ring on the SLAC site. In 1977, construction began on the positron–electron project (PEP), a joint project between SLAC and the Lawrence Berkeley National Laboratory (LBNL). The machine opened for scientific use in 1980 (Panofsky 2007: 137). PEP never produced the anticipated results and ceased operation prematurely in 1991 due to budget cuts (Hamilton 1992: 432). However, by that time, SLAC had revived its reputation with the inventive Stanford Linear Collider (SLC) machine. Construction of the SLC, essentially a machine that allows two beams from the original SLAC linac to deviate in two tunnels and then collide head-on, started in 1983 and concluded in 1989 (Panofsky 2007: 140). The inventiveness of the concept made it technically risky, experiencing delays and unstable performance for several years (Plummer 2008: 18), but the heavy investment involved gave the SLC highest priority at SLAC, at the expense of the PP programs at PEP and SPEAR and, most of all, the SR activities.

The number of users of SSRP had grown a level where SSRP was unsustainable as a mere external scientific project at SLAC, and it had to be given a stable organization. The program was turned into an independent laboratory within Stanford University and renamed the SSRL. In 1982, the laboratory's federal-level stewardship was taken over by the Department of Energy (DOE), the successor of the AEC charged with supervising SR activities nationwide. More importantly, however, in 1979 SSRL was granted exclusive use of 50% of the running time of SPEAR (Cantwell 1994a: 44). Operation of SPEAR was still under SLAC control, and the linac was used for simultaneous injection of particles to SPEAR, PEP, and eventually the SLC. PEP operations and the instability of commissioning the SLC caused a veritable second 'X-ray drought' for SSRL throughout the 1980s, with an all-time low in 1986 when no radiation was delivered to its experimental stations at all (Hallonsten 2009: 124). In 1989, an external scientific review of SSRL concluded that, unless the priorities of SR research and the PP program at SLAC were renegotiated, the SSRL would slowly fade into oblivion, which would mean a waste of the investments and competence that had been built up (Hallonsten 2009: 125).

With the blessing of Burton Richter, who would become SLAC director in 1984 when Panofsky retired, SSRL was made a division of SLAC in 1992. In this way, the once single-purpose PP lab became multi-purpose and SPEAR became an all-SR machine (Panofsky 2007: 126; Hallonsten 2009: 131). A separate injector machine for SPEAR was constructed, allowing SSRL full control over SPEAR operations (Cantwell 1994b: 6). Additional improvements in the late 1990s—the SPEAR 3 upgrade—turned SPEAR into a facility that was on a par with modern SR sources, which meant a significant improvement in the capability to serve life sciences experiments (Hallonsten 2009: 126). The SLC continued to produce physics, and an upgrade of the PEP facility (to PEP-II) started in 1996 and was finished in 1998 (Hallonsten 2009: 148). The 1990s were a decade of relatively peaceful coexistence for PP and SR at SLAC.

SR had grown tremendously since the first trial runs at various labs in the 1960s and 1970s, and a boom in both the scientific utility and technical performance of existing sources occurred in the 1990s.[2] At SLAC, plans were starting to emerge to make use of the gathered competence and resources on site for the next leap in performance. So-called free-electron lasers (FELs) emerged on the drawing board as the next generation SR source concept, and these FELs typically made use of very long linacs as their central component. Plans for turning the SLAC linac into a FEL were first drafted in 1992 and matured gradually during the 1990s (Hallonsten 2009: 143). Though judged both exciting and promising, the LCLS concept posed a direct threat to the PP activities at SLAC, not only locally on site, but also in the federal budget and national labs' strategy—at least that was the interpretation among particle physicists. Therefore, plans remained tentative until 1999, when two DOE-led reviews endorsed the idea, which turned the LCLS project into a national priority (Hallonsten 2009: 144–5). In 2002, the DOE decided to move forward with a full-scale user facility and not only the test machine that SLAC had suggested (Hallonsten 2009: 145). Using the SLAC linac, which was at this point abandoned by the SLC, reportedly saved 'hundreds of millions of dollars' compared to building the LCLS on a green field site (Woods 2006: 12).

The LCLS was designed so that it would not monopolize the linac, but allow for simultaneous operation of PEP-II. Nonetheless, it was obvious to most spectators that the main experimental facility at SLAC would be the LCLS (complemented by, of course, the SSRL) after scheduled shutdown of PEP-II in late 2008. Despite hard pressure from the SLAC PP community for a new PP project, the strategy of DOE was to make SLAC primarily a PS lab. When the PEP-II was shut down in 2008 six months prematurely due to federal budget cutbacks, the shift occurred at full speed. Prominent SLAC physicists openly criticized Persis Drell, their director, for not putting up more of a fight with the DOE, but others praised her leadership, realizing that she only did what was best for the lab in the long term (Cho 2009: 223).

On 10 April 2009, the LCLS began operation (Cho 2009: 221). Besides the SSRL, the LCLS is now the main experimental facility at SLAC. PP has not been completely abandoned; as mentioned, SLAC is involved in both data collection and processing from CERN and is planning for the future international linear collider (ILC). In 2003, the Kavli Institute for Particle Astrophysics and

Cosmology opened at SLAC with the purpose of studying particles in space (Irion 2003: 492). However, as its name suggests, SLAC is primarily a national accelerator laboratory, and as such, it can be argued that it is a *de facto* single-purpose PS lab, as the only accelerators operated on site are used solely for PS. The stated goal of SLAC and Stanford University is to be:

> . . . the world's leader in the new multidisciplinary field of PS, the study of matter through its interaction with photons. (SSRL 2007: 1)

4. A brief history of DESY

The German Electron Synchrotron (DESY) is located in the Bahrenfeld area of Hamburg. The laboratory is a dual-mission research center of the Helmholtz Gemeinschaft for PP/particle astrophysics and PS. DESY operates two main user facilities for PS: the SR source (PETRA III) and the free-electron laser (FLASH). In addition, DESY is the main shareholder (53.6%) in the European company constructing an X-ray free-electron laser (XFEL) facility, which is partly on the DESY campus. The DESY PP division and particle astrophysics division, which is located on a separate campus in Berlin-Zeuthen, constitute the other part of DESY. Organizationally, DESY is a private foundation with two main sponsors, the Federal Ministry of Education and Research and the Senate of Hamburg City, holding the majority in the administrative board that approves major organizational strategies and decisions.

The origins of DESY date back to the recruitment of nuclear physics professor Willibald Jentschke to the Institute of Physics at Hamburg University in 1955. Jentschke had moved to the USA after World War II, and was the director of the Cyclotron Laboratory at the University of Illinois at Urbana-Champaign. Jentschke's negotiations with both the Senate of Hamburg City (the main sponsor of Hamburg University) and the Federal Ministry for Atomic Matters regarding the endowment of his chair and the building of a 7.5 GeV electron synchrotron were successful, not only because the International Symposium on High Energy Particle Accelerators at CERN strongly recommended the building of an electron synchrotron under his leadership, the so-called 'Geneva memorandum' (Habfast 1989: 8–14), but also because the Federal Ministry regarded the new synchrotron as an important step towards re-establishing the country's global leadership in nuclear physics (Habfast 1989: 2; Lohrmann and Söding 2009: 3–8). Consequently, the Federal Ministry funded the lion's share of DESY, whose building costs were projected initially at 60 million Deutschmark (DM) but later increased to approximately 110 million DM. Construction started in 1959, and in 1964 DESY began operating its first synchrotron machine for nuclear and PP research. Jentschke became the first director of DESY and remained in that position until 1970.

As early as 1964, a member of the DESY directorate, Peter Staehelin, entered the field of SR with a large grant from the German Research Foundation (DFG) that covered construction costs for laboratory buildings and an experimental station at DESY (Lohrmann and Söding 2009: 29). The DESY directorate decided to substantially enlarge the lab's infrastructure by building a new linac as an injector for the ring accelerator (operation started in 1969) and a storage ring facility in 1967 and 1968, respectively. When this machine, called DORIS (Doppel-Ring Speicher [transl: double-ring storage]), became operational in 1973, Jentschke was Director General of CERN (starting in that position in 1971) and had been succeeded by Herwig Schopper (in office 1971–80). Unfortunately, DORIS experienced persistent beam instabilities that effectively blocked the research ambitions of many SR users (Lohrmann and Söding 2009: 240) and impeded the PP experiments. Satisfactory stability was achieved in 1977 when DORIS was converted into a single-ring operation, and it was improved further when a separate injector for the much larger Positron-Elektron Tandem Ring Anlage (PETRA [transl: positron-electron tandem ring facility]) went into operation in 1979, relieving DORIS of this duty (Lohrmann and Söding 2009: 79, 90).

After the mid-1970s, the growing national and international community for SR placed increasing demands on the facilities at DESY, which led to the construction of new buildings and significant investments in instrumentation for the SR program at DESY. In 1975, the DESY directorate decided to build the PETRA accelerator for PP at a projected cost of approximately 108 million DM. Around the same time, the SR advisory council at DESY submitted a proposal to the Federal Ministry to build a dedicated facility for SR. Though the DESY directorate wanted such a dedicated facility to be separate from the main lab organization, the funders decided to establish it as a division of DESY with a separate budget and its own facilities. Hamburg Synchrotronstrahlungslabor (HASYLAB [transl: Hamburg Synchrotron Radiation Laboratory]) was created in 1977 and given full control over all SR activities at DESY, which grew significantly at the end of the 1970s, and by 1981 one-third of the beam time at DORIS was allocated directly to HASYLAB (Lohrmann and Söding 2009: 242–4). However, the HASYLAB organization commanded relatively small resources; by 1985 the number of staff grew from 8 to 38 and DESY employed an approximate total of 1,000 people, and the operating costs of HASYLAB grew from less than 0.5% of the total DESY budget to approximately 2% during the same period.

PETRA, the new PP flagship at DESY, went into operation in 1978 and soon became a success by spurring the momentous discovery of so-called gluons. In 1986,

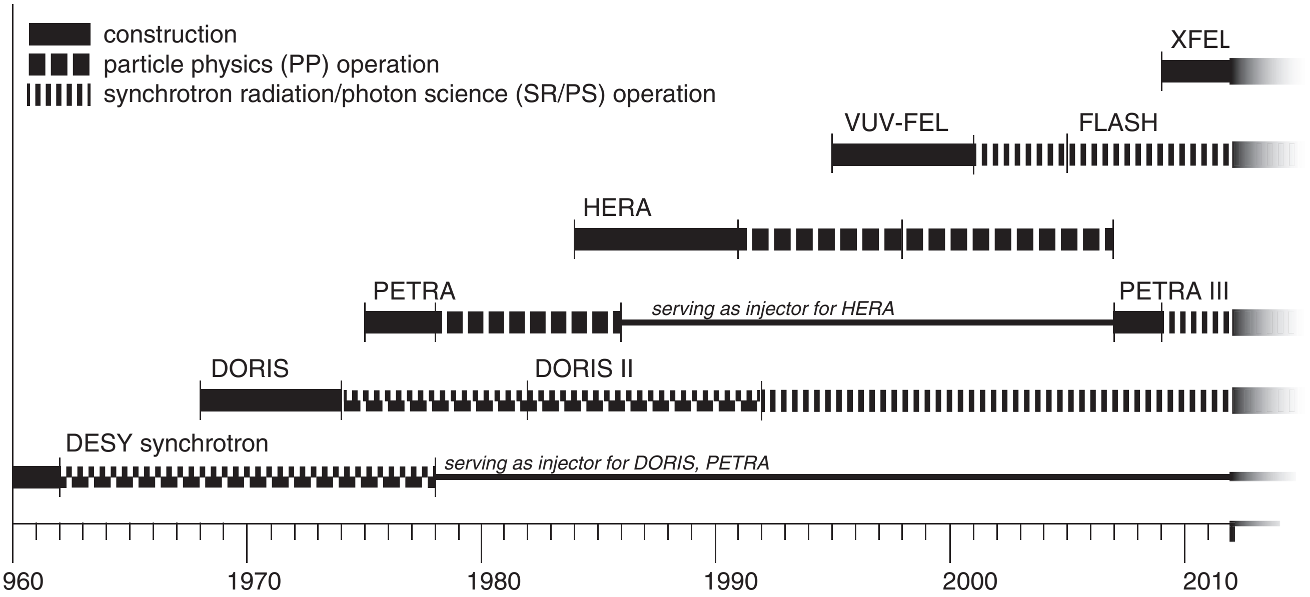

Figure 2. Timeline of major accelerator facilities at DESY (adapted from Lohrmann and Söding 2009).

PETRA was converted to the injector for the biggest machine in DESY's history, the Hadron Electron Ring Facility (HERA) (see Fig. 2). In contrast to DORIS and PETRA, which had focused on electron positron collisions, HERA was built to explore electron proton collisions. This shift was related to CERN's decision in the late 1970s to invest in the Large Electron Positron Collider (LEP), the 'natural successor' to PETRA (Lohrmann and Söding 2009: 118). The construction of HERA started in 1983, and it went into operation in 1992. HERA competed very well with machines at CERN and Fermilab, which can be considered to be DESY's main global competitors in PP at the time.

Even though the construction and operation of HERA meant an extraordinary investment in capital equipment and human resources (approximately one billion DM), DESY's directorate and advisory council decided to simultaneously upgrade and expand HASYLAB, including the installation of wigglers and undulators at DORIS, which significantly enhanced its performance. This expansion allowed a considerable growth in the number of external users at HASYLAB, which in turn created demand for even more investments and more dedicated beam time at DORIS (Lohrmann and Söding 2009: 264). In this regard, the upgrade of DORIS and its dedication to the SR community in 1993 was a turning point in the history of DESY.

The dedication of DORIS to SR was an important step in the overall transformation of DESY. A second important step with regard to DESY's gradual shift occurred in 1993, when an upgraded PETRA opened its gates to SR, and in 1995 when one-third of its beam time was dedicated to SR. That year, approximately 1,700 users from all over the world and from numerous disciplines, including molecular biology, material sciences, and chemistry, populated the SR experimental stations at DORIS and PETRA (Lohrmann and Söding 2009: 264). In the mid-1990s, the DESY Scientific Council and Advisory Board decided to build a free-electron laser facility, later named FLASH, which was a major step forward for PS that opened up completely new experimental opportunities. This new machine went into operation in 2001.

The mid-1990s were also important in that Björn Wiik, a Norwegian physicist and leading scientist at DESY since 1972 and one of the protagonists of HERA, was named the fourth director general of DESY (in office 1993–9). Wiik worked purposefully to forge a closer alliance between the PP and SR/PS communities at DESY in the late 1990s. Concretely, the alliance led to the Tera-electronvolt Energy Superconducting Linear Accelerator (TESLA) proposal, to which more than 1,100 scientists from more than 300 research organizations in 36 countries contributed. TESLA was a new facility envisioned to be built outside Hamburg by DESY, including a new linear collider for PP and an XFEL facility for PS, and designed to sustain the DESY scientific agenda and secure a long-term, globally leading position for the lab in both realms (Lohrmann and Söding 2009: 315–21).

However, the TESLA proposal was not met with unanimous support from the German government. In 2003, during the tenure of Wiik's successor, Albrecht Wagner (in office 1999–2009), the Federal Ministry of Research and Education announced its support for the XFEL part of the project and declined to support the linear collider (PP) part. This decision was coupled with another decision by which the Federal Ministry allocated €225 million for the conversion of PETRA into a dedicated SR facility, later called PETRA III (see Fig. 2). Altogether, these decisions meant an allocation of approximately €1.3 billion in fresh money from the Federal Ministry of Research and

Education to DESY for further development of its PS program, effectively phasing out its support for the DESY PP program (Lohrmann and Söding 2009: 322–30). Only a few years later, in 2007, HERA ceased operation. In contrast to DORIS and PETRA, HERA has thus far not been converted into any new scientific use or utilized as part of new facility projects (cf. PEP at SLAC).

Though HERA was shut down, and no facility for PP is currently in operation at DESY, the PP program has not been deserted. Data from HERA is still being processed, and DESY scientists are heavily involved in both data collection and processing for CERN experiments and planning for the future ILC project, which is partly a continuation of the TESLA linear collider. Nevertheless, all new large-scale activities started at DESY since the 2000s have been devoted to PS, and it can be argued that DESY is, or will eventually be, a *de facto* single-purpose SR/PS laboratory. In 2009, construction of the XFEL started and PETRA III began operation. During the same year, Helmut Dosch, a solid state physicist by training, was named director general of DESY, the first DESY director not recruited from the PP community.

5. Multi-level processes of institutional renewal

The short histories of SLAC and DESY show that neither of these two labs experienced abrupt changes in their research missions, budgets, organizational structures, or leadership: instead, incremental steps were typical of their shift from PP to SR/PS. Similarly, though the shift towards SR/PS initially occurred at the periphery for both labs, these new scientific activities continued to expand, becoming the two labs' new intellectual core. In fact, the shutdown of HERA (2007) at DESY and PEP-II (2008) at SLAC can be interpreted as the final visible steps of an irreversible shift away from PP that both labs experienced for more than 30 years. This development should also be considered in the light of systemic changes to (Western) science policy since the 1970s, shifting priorities away from the nuclear threat/promise and Cold War competition and towards issues of competitiveness, sustainability, and the expectations surrounding the advent of nano and biotechnologies, as shown by the changing status of Big Science projects in politics and wider society (Jacob and Hallonsten 2012; Elzinga 2012; Westfall 2008a; Stevens 2003). Thus, the transformation of both DESY and SLAC can be characterized as simultaneously incremental and discontinuous. Rather than being subject to radical and spontaneous change, both labs experienced gradual change over an extended period of time. However, their missions and research portfolios changed dramatically when viewed from both ends of historical development: initially, PP was the defining scientific field, but it was effectively replaced by SR/PS activities, which now dominate both labs. Therefore, in terms of the typology for various forms of institutional renewal developed by Streeck and Thelen (2005) and illustrated in Fig. 3, both DESY and SLAC are exemplars of gradual transformation.

However, gradual transformation can occur through various processes of change. Building on our theoretical framework developed for institutional renewal in research (Heinze and Münch 2012), which borrows from historical institutionalism and path dependency theory (Thelen 2003; Streeck and Thelen 2005; Streeck 2009), we distinguish four processes of gradual transformation at the organizational level (see Fig. 4). The relevance and aptness of this framework has been demonstrated by previous analyses of SNLs at the systemic level (Hallonsten and Heinze 2012). Layering processes occur when positions or units that represent new research fields are added to the existing research capacities. Typically, layering occurs in the context of growth, either in monetary terms or in terms of scientific staff. In contrast, dismantling occurs when existing research capacities are abandoned without simultaneously establishing new positions or units representing new fields; for example, when nobody is recruited into the vacant position after a professor's retirement, or when a

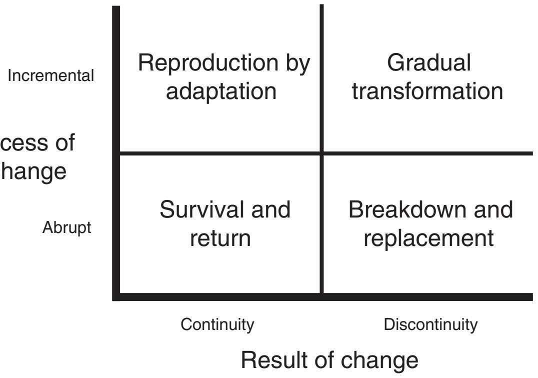

Figure 3. Typology of organizational/institutional change (Streeck and Thelen 2005).

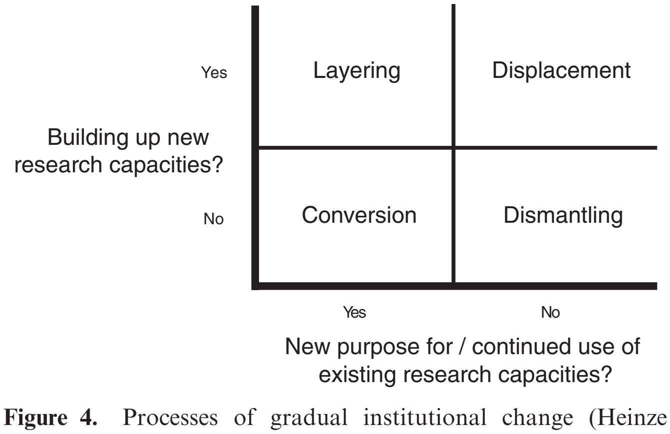

Figure 4. Processes of gradual institutional change (Heinze and Münch 2012).

department is closed. Displacement occurs when existing research capacities are replaced by new structures: for example, when a retired professor's position is rededicated to another research field or discipline, or when a costly scientific instrument is replaced by a new one. Conversion is of particular interest for the discussion of adaptation and change because existing structures are given new purposes or oriented towards new goals and missions: for example, when a scientist migrates to another research field or when an existing scientific machine is upgraded or rebuilt in order to be useful in a new disciplinary context.

Distinguishing between the four processes of change requires clearly spelling out both the time horizon and the analytical level. For example, short-term changes might appear as dismantling, whereas the same developments would appear as displacement from a long-term perspective. We distinguish between organizational structures, research infrastructures, and scientific fields to capture the different analytical levels on which processes of change might operate.

The key to using these categories of change processes for analyzing actual cases is to retain a flexible and multi-level view of research organizations, their institutional context, and their change. The two cases under study are complex entities made up of multiple organizational levels and divisions, and they serve various scientific fields. Therefore, the range of possible perspectives on their change is broad. In the following analysis of their histories, we will use a tentative taxonomy of change in organizational structures, research infrastructures, and scientific fields, which allows for different processes of change (see Fig. 4) to be simultaneously active in the formative events and processes in the histories of the labs. This approach also allows historical events and processes to be interpreted differently, with respect to the processes of change, from different perspectives, and even at different points in time. Our approach also corresponds to three sources or drivers of change and renewal in a complex Big Science lab context: organizational structures of lab management and leadership, research infrastructure based on processes of national policymaking (as major new pieces of infrastructure are appropriated at a national policy level), and scientific fields according to the dynamics of the cognitive/intellectual evolution in science.

The organizational structures of the DESY and SLAC can be interpreted in a straightforward manner. Both laboratories started out as single-purpose PP labs with a central lab organization and different auxiliary activities carried out by different types of user groups. Both the SSRP at SLAC and the early SR activities at DESY can be interpreted as peripheral activities carried out by external user groups at the respective labs. The chief transformation of the two labs on the formal organizational level can be understood simply as layering. In the late 1970s, HASYLAB and SSRL were founded as distinct entities, and in 1999 and 1992 they became organizational divisions of DESY and SLAC, respectively. This layering process has been confirmed by an analysis of the organizational charts of the two labs over the years. Smaller variations, such as the renaming of entities/divisions and some restructuring, have occurred, but in essence the two labs have undergone layering processes (see Fig. 5). PP divisions still exist within the respective lab organizations, but naturally, essential change has occurred within these simple organizational divisions. The underlying assumption of this paper is that the two labs have been profoundly transformed during the past few decades, not merely expanded with another layer of activities on top of an unchanged core mission. Therefore, the analysis of the research infrastructures and scientific fields at the two labs is more complicated than the analysis of the organizational level.

In terms of their research infrastructure (see Figs 1 and 2), both DESY and SLAC have, over the years, operated a number of different accelerator facilities for both PP and SR/PS purposes, and occasionally PP and SR/PS have shared facilities. The DORIS and SPEAR storage rings are prime examples of the latter case. Both rings were conceived and built as PP machines, have been used in parallel for PP and SR/PS, and were eventually switched over completely to SR/PS. Thus, the overall 40-year histories can both be interpreted, in a somewhat simplified manner, as examples of conversion on the infrastructure side. The histories are not to be seen as displacement, as the machines as such remain intact and have not been replaced, only partially rebuilt. During an intermediary time period, an alternative interpretation is of course layering, as both machines were used for dual purposes before being taken over completely (converted) by SR/PS (see Fig. 6).

DORIS was also shut down recently (2012), which seems to be a case of dismantling. However, one could argue that

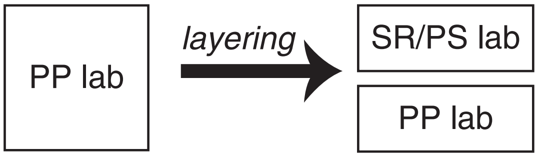

Figure 5. Changes to the organizational structures of DESY and SLAC.

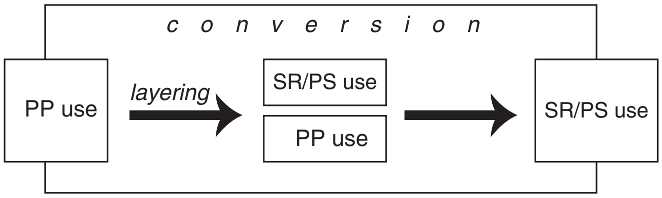

Figure 6. Changes to DORIS and SPEAR machines as research infrastructures over 40 years.

the major reason behind the shutdown of DORIS is that PETRA III is now the state-of-the-art facility for SR/PS at DESY, rendering the SR/PS program at DORIS partially obsolete. Therefore, the shutdown of DORIS should be interpreted in the context of other SR/PS machines (PETRA III). Viewed from this within-field angle, DORIS has been displaced by PETRA III as a research infrastructure.

PETRA is itself a curious case. Opening in 1978, PETRA was used for PP experiments until 1987, when it was converted into a pre-accelerator for the much larger HERA. Thus, this case appears as dismantling if viewed as an experimental facility within PP. Taking a longer view, however, (see Fig. 7) shows that PETRA underwent conversion into a dedicated SR/PS machine (PETRA III) through the lower-level conversion of the pre-accelerator into a new user facility. It should be noted that conversion can occur on different levels and within different time frames, depending on the viewpoint.

HERA is probably the most distinct example of dismantling, as it was shut down in 2007. The speculation is that HERA could be used for SR/PS in the future, but at the moment such plans are nowhere near materializing. In contrast, both the FLASH and XFEL facilities are new infrastructure projects at DESY, not conversions of old machines. Thus, from the infrastructure point of view they can only be viewed as cases of layering.

In regards to the SLAC machines other than SPEAR, the original linac was converted into a pre-accelerator (injector) in 1974 and used for all subsequent facilities (except SPEAR after 1990). The SLC can also be viewed as a conversion of the original linac, later converted into a pre-accelerator for PEP-II (1998), and eventually converted into the LCLS (2004–9) (see Fig. 8). Just as with PETRA (see Fig. 7), the conversion occurred on different levels. Here, the original linac underwent overall conversion that, viewed in 2012, ends with the LCLS but is essentially open-ended as we do not know if there are additional future uses for the basic linac infrastructure. This overall process is, in turn, made up of several shorter-term steps of conversion. Importantly, scientifically the SLC is replaced by PEP-II, but PEP-II is a completely different machine (see Fig. 1); the SLC makes direct use of the linac, whereas PEP-II is a mid-1990s upgrade (conversion) of the PEP ring opened in 1980. PEP-II was shut down, hence dismantled, in 2008. No overall process like that for PETRA (see Fig. 7) has yet been identified, but plans exist to turn PEP into an SR machine, and so in some years time a frame representing an overall conversion process could be added to Fig. 9.

For scientific fields, analyzing processes of institutional renewal is also a complex task, which is probably even more difficult. Scientific programs and fields are partly tied to the operation of the facilities discussed above as well as partly independent activities. The processes of institutional renewal should be viewed with regard to the scientific activities at DESY and SLAC against the background of the infrastructure, or as varieties of infrastructure activities.

The DORIS and SPEAR examples are quite simple. Here, we can rightfully state that the renewal on the scientific field side initially follows the layering process on the infrastructure side, but evolves into displacement in the long run. Though PP was the dominant scientific discipline initially, SR/PS entered as scientific activities at both DORIS and SPEAR early on in their careers as PP machines. PP and SR/PS were parallel activities at both machines for almost 20 years, which makes their first two decades of history examples of layering. Finally, however, when DORIS and SPEAR were dedicated to SR/PS, PP was dismantled and, seen in a broader perspective, effectively displaced (see Fig. 10). It should be noted that the partial dismantling of DORIS and SPEAR shown in Fig. 10, refers to scientific use and not the machines themselves, whose transformation are represented in Fig. 6 without any dismantling process being identified.

The same can be said, in principle, about the SLAC linac/SLC that were scientifically displaced by LCLS,

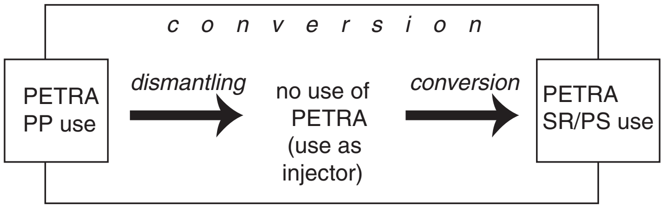

Figure 7. Changes to the PETRA machine over 30 years.

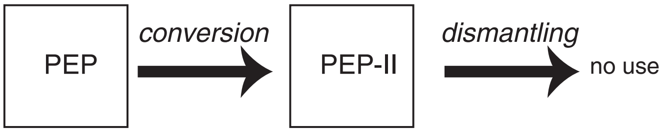

Figure 9. Changes to the PEP machine over 30 years.

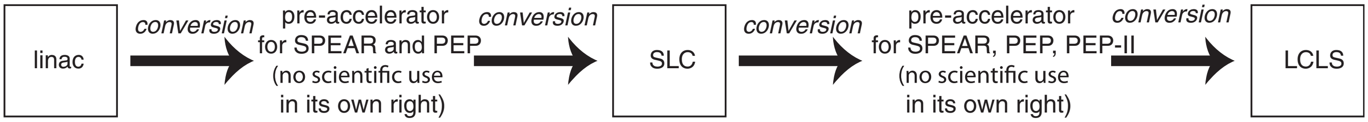

Figure 8. Changes to the SLAC linac over 40 years.

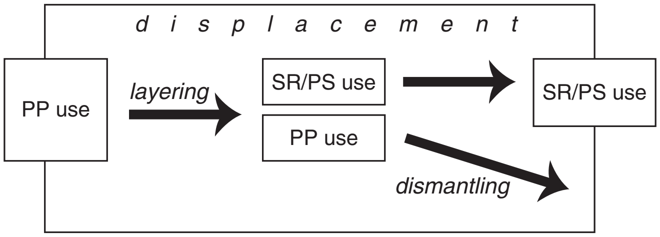

Figure 10. Changes to DORIS and SPEAR machines from the perspective of scientific fields over 40 years.

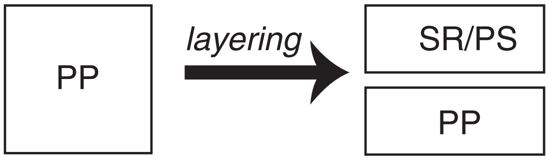

Figure 11. Long-term, macro-level changes to DESY and SLAC from the perspective of scientific fields.

and PETRA, which was scientifically displaced by PETRA III in the long term. Interestingly, the scientific programs at PEP-II and HERA have not quite been dismantled. At the time of writing, data from these machines are still being processed and no signs indicate dramatic downscaling of these activities. Naturally, one asks how long the scientific programs can continue without operating a machine, but this question will have to be answered in the future. Clearly, from an overall level, if viewing the primary missions of the labs as running accelerator-based scientific facilities for experimental science, the long-term transformation can be interpreted as one of displacement—both DESY and SLAC once ran accelerators exclusively for PP, and now they both run accelerators exclusively for SR/PS.

However, this interpretation is still very much tied to machine operation. The scientific programs of the two labs can be viewed at a separate level of analysis whereby maintenance of a scientific program in PP plus the new scientific programs in SR/PS (regardless of the operation of facilities) constitute layering. To this day, both DESY and SLAC maintain scientific programs in PP, though in one sense these have been converted to analysis of data from CERN (both labs) and the new theoretical and partly experimental particle astrophysics program at SLAC and DESY-Zeuthen. Thus, on a macro level, the portfolios of scientific fields at DESY and SLAC have been transformed by layering—SR/PS has been added to a continuing PP program (see Fig. 11). The similarity between Figs. 11 and 5, illustrating the long-term changes to the DESY and SLAC organizations, is no mere coincidence, but rather a reflection of the already emphasized points that the two organizations were once put in place to run single-purpose laboratories and have gradually adapted in line with major scientific developments.

6. Conclusions

We were able to identify several occurrences of all four processes of gradual institutional change (see Fig. 4) on several different levels in both cases which we have examined. Furthermore, the choice of time perspective clearly added another dimension to the use of the processes as tools in analyzing the histories of DESY and SLAC and their gradual transformations. The basic premise of this paper is that attention should be paid primarily to the long-term perspective, because then the consequences of the gradual incremental processes of change are found. Though our prime interest is not the momentary and radical events of change that are discernible when studying a short time period, they also need to be accounted for as a contrast and part of the multi-level analysis that we have proposed and used in this paper.

The main conclusion is that the complexity of large research centers like DESY and SLAC demands a multi-level analysis of processes of institutional change. We have proposed that for these specific case studies, the three levels of organizational structure, research infrastructure, and scientific field are relevant and adequate to capture the complexity of the organizations under study and their changes. However, this strategy is worth a trial in other studies of change in science. Clearly, as this paper has shown, processes of institutional change cannot be used as simple labels for macro structures, such as SNLs or individual national labs; multi-level analysis is necessary. Furthermore, the combination of the three levels is necessary to unveil and understand the processes of change. Scientific instruments and infrastructures can be said to be, by definition, generic and have an inherent potential to move across disciplinary spectra and find new applications (Joerges and Shinn 2001; Shinn and Joerges 2002). The opportunity to exploit such new applications is heavily dependent on organizational structures and the relative strength of proponents of different scientific fields in different institutional contexts at different points in time. Here, we also found important implications for science policy studies. Our analysis shows that this complex and multi-level process of renewal of the Big Science labs (DESY and SLAC) occurred due to the interaction of different drivers of change, and that all three levels, as well as their interaction in long-term processes of renewal, require careful analysis. As a highly visible, costly, and potentially impactful area of science policy and funding, Big Science continues to pose a challenge to governments seeking to keep up with international competition in science and technology. Thus, the renewal of Big Science labs in accordance with major changes in global political, economic, and technoscientific regimes is an urgent topic of study. This paper contributes to this study by showing how gradual transformation occurs on different levels and through the operation of different mechanisms at various levels and points in time.

Fine-grained analysis of the mechanisms and what underlies them is absent in this paper but is part of the research agenda. Topics not covered here but of clear overall interest include, but are not limited to: first, the causal connections between the three levels of organizational structure, research infrastructure, and scientific field in driving overall change; and second, the role of management/leadership, policymaking, and cognitive evolution of the sciences in invoking change. Although beyond the scope of the current paper, we see clear opportunities for adapting the typology of processes of institutional change, as illustrated in Fig. 3, in combination with a multi-level perspective of research organizations in science and change processes in several other types of organizations, fields, and entities in science.

Acknowledgements

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Notes

1. The lab was renamed in 2008, from Stanford Linear Accelerator Center (SLAC) to SLAC National Accelerator Laboratory, with ‘SLAC’ no longer an acronym but still the short name of the lab, traditionally pronounced ‘slack’ (Cho 2008: 515).
2. The number of users worldwide had increased as new, mature, ‘third generation sources’ opened in several countries, including Germany, Japan, France, Switzerland, Canada, Sweden, Italy, and the UK, and later Australia, China, and Brazil (Hallonsten 2009: 89–91).

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