NATIONAL LABS

For a Famous Physics Laboratory, A Quick and Painful Rebirth

Renowned for particle physics experiments, SLAC National Accelerator Laboratory has reinvented itself as a multipurpose lab featuring the world's first x-ray laser

MENLO PARK, CALIFORNIA—When the pipe exploded, it packed the wallop of two sticks of dynamite. The 13 September 2007 mishap could have maimed or killed technicians here at SLAC National Accelerator Laboratory. It certainly jolted Persis Drell, the particle physicist who had become acting director of the famed lab just 4 days earlier.

The blast resulted from the kind of mistake anyone might make: Welders cutting into a steel water pipe ignited fumes from epoxy used to attach a plastic extension the day before. But Drell was already in a tricky position. Renowned as a center for particle physics, SLAC had begun a wrenching shift to a broader mission emphasizing x-ray studies for fields such as materials science and structural biology. The lab was also under fire from its owner, the U.S. Department of Energy (DOE), for management deficiencies and safety lapses, including a nearly fatal electrical accident in 2004. The blast was another boulder in a rockslide falling on the lab. Yet, Drell says, "I joke, the explosion was the best thing that ever happened to us."

The blast proved that things had to change, Drell says. She feared that if the lab had another accident like the one in 2004, DOE might shut it down for good—a fear that Paul Golan, manager of DOE's site office at the lab, calls "not unreasonable." So Drell and Golan began meeting every morning to plan how to head off incidents like the explosion. Although only the acting director, Drell also began rearranging management at the lab, which is operated by Stanford University in neighboring Palo Alto, California. In December 2007 she became director, tasked with guiding SLAC through its scientific and managerial metamorphosis. "It's hard for me to imagine that you could make a transition more quickly," she says. "It's been a bit brutal."

Like a butterfly cracking its chrysalis, SLAC has shed its former self. On 7 April 2008, physicists turned off the lab's last particle smasher. On 10 April 2009, they turned on its new flagship facility, the world's first x-ray laser. Dubbed the Linac Coherent Light Source (LCLS), the laser shines a billion times brighter than any previous x-ray source. First experiments with it began last week, and with the shift in science come equally dramatic changes in the management and culture of the storied lab.

Forward! Director Persis Drell has pushed SLAC through its speedy transformation.

CREDITS (TOP TO BOTTOM): SLAC; BRADLEY R. PLUMMER/SLAC

SLAC officials are rearranging everything, including the furniture—particle physicists' offices in the lab's main building are being converted into labs to support the LCLS. Even some of the lab's most eminent particle physicists say the changes are necessary. "Labs like SLAC are institutions for the long term, and they have to evolve," says Burton Richter, a former SLAC director and one of the lab's three Nobel laureates.

But other particle physicists fault Drell for not fighting to keep their last collider, called PEP-II, running or pushing for another project to replace it. They say that whereas past directors fought for the lab's autonomy, Drell has embraced DOE's micromanagement. "It seems to me that we're largely being run out of Washington," says SLAC veteran Martin Breidenbach. "There's little evidence of pushing back."

One sharp corner

DOE's nine other science labs have faced changes in their missions as well, particularly as particle physics facilities have shut down. In 1979, DOE closed down a proton accelerator known as the Zero Gradient Synchrotron at Argonne National Laboratory in Illinois after a higher energy machine turned on 40 kilometers away at Fermi National Accelerator Laboratory (Fermilab) in Batavia. Not long after, Argonne disbanded its 400-member accelerator physics division, recalls Ronald Martin, who was then division director.

The lab went without a major accelerator until 1988, when it won DOE approval for an x-ray source based on a circular accelerator called a synchrotron, in which the particles radiate as they circulate. The $812 million Advanced Photon Source revved up in 1995 and is Argonne's largest facility. "Without that, it would have been a terrible disaster" for the lab, Martin says.

Similarly, in 1983, DOE canceled the half-built ISABELLE proton collider at Brookhaven National Laboratory in Upton, New York, to shift resources to an even bigger atom smasher, the Superconducting Super Collider (which, ironically, was canceled during construction 10 years later).

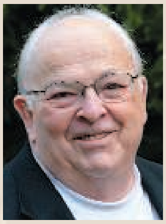
"We had 300 or 400 hundred people working on ISABELLE, and we had to let most of them go," recalls Nicholas Samios, a particle physicist who was Brookhaven's director at the time. Brookhaven waited until 1990 to get the go-ahead for a different collider to smash heavy atomic nuclei for studies in nuclear physics, the $616 million Relativistic Heavy Ion Collider, which has been running since 2000.

In contrast, SLAC has not had to languish without a major facility. LCLS construction started in 2006, 2 years before SLAC's last particle collider shut down. However, SLAC is also facing a more dramatic transformation. Both Argonne and Brookhaven were already multipurpose labs at which particle physics accounted for only a fraction of the research. In contrast, since its founding 47 years ago, SLAC has focused almost exclusively on particle physics, making its shift far more drastic. "If you bet all your money on one thing and all of a sudden that one thing doesn't have a future, then you have a problem," Samios says.

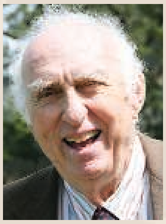
Fortunately for SLAC physicists, the key to their future in x-ray physics already lay before them: the 3-kilometer-long linear particle accelerator, or linac, that has been the backbone of the particle physics program since the lab's inception.

Nobel Prize-winning SLAC-kers

Richard Taylor—cited with two others, discovered that protons contain particles called quarks



Burton Richter—cited with one other, discovered the hypothesized charm quark



Martin Perl—discovered the tau lepton, a massive cousin of the electron.

Stanford University biochemist Roger Kornberg did prize-winning work at SLAC's synchrotron x-ray source. SLAC's BaBar experiment confirmed the prize-winning prediction of Japanese particle theorists Makoto Kobayashi and Toshihide Maskawa.

The light at the end of the tunnel

Lining one side of a broad tunnel and gleaming beneath the overhead lights, the LCLS looks powerful. On their waist-high mounts, 33 magnets called undulators lie connected end to end, each a cylinder 3.4 meters long and 30 centimeters in diameter. A beam of high-energy electrons from the linac enters one end of the chain; a laser beam of x-rays emerges from the other. The LCLS is an x-ray source unlike any before, scientists say. It's also a nifty trick done without mirrors.

A conventional laser consists of two mirrors, one of which lets some light through. Between them sits a material that emits photons, such as a crystal that fluoresces when zapped with electricity. The photons bounce between the mirrors, and as they pass through the material, they stimulate the atoms in it to emit more light. That feedback creates a torrent of photons moving in synchrony that emerges through the imperfect mirror as the laser beam.

Mirrors for x-rays don't exist, however, so the LCLS works in a different way. Each undulator consists of two rows of 224 small magnets, one above and one below the pipe that carries the electrons. Neighboring magnets point in opposite directions, and their fields cause electrons passing down the pipe to wiggle from side to side and radiate x-rays. The x-rays also whiz down the beam pipe, and they push the electrons into tiny bunches. "Now each bunch radiates as if it were a single electron with an enormous electric charge," which greatly amplifies the x-rays, says John Galayda, the SLAC accelerator physicist who directed LCLS construction.

The 90-micrometer-wide electron beam must overlap with the nearly-as-narrow x-ray beam through the entire 130-meter row of undulators, a challenge that led some researchers to question whether the LCLS would ever work. On 10 April, Galayda's team put all doubts to rest, producing the world's first x-ray laser beam after less than 2 hours of trying. "It was a really, really nice experience," Galayda says with a wide smile.

SLAC isn't a newcomer to x-ray science. Since 1973, the lab has run a relatively small synchrotron x-ray source, one of the first. But the LCLS may put the lab on the top of the heap. It could enable researchers to make "movies" of chemical reactions in progress, determine the structure of proteins from a sample of one molecule, or probe matter under conditions found at the center of planets.

The LCLS cranks out x-rays with a wavelength of 0.15 nanometers—short enough to probe the atomic-scale structure of materials—in pulses lasting only 2 millionths of a nanosecond. Such short pulses should allow experimenters to snap the x-ray equivalent of stop-action photos of chemical reactions as they occur, says Joachim Stöhr, an x-ray physicist and associate director for the LCLS at SLAC. "That's one big aspect of the LCLS," he says. "It couples the atomic scale with the ultrafast."

The LCLS has already attracted far more proposals for experiments than it can accommodate and is drawing top researchers. "I came here for the LCLS," says Philip Bucksbaum, an atomic physicist at SLAC and expert in ultrafast lasers who arrived in 2006 from the University of Michigan, Ann Arbor. "It's a chance in about 10 lifetimes."

The outsider from within

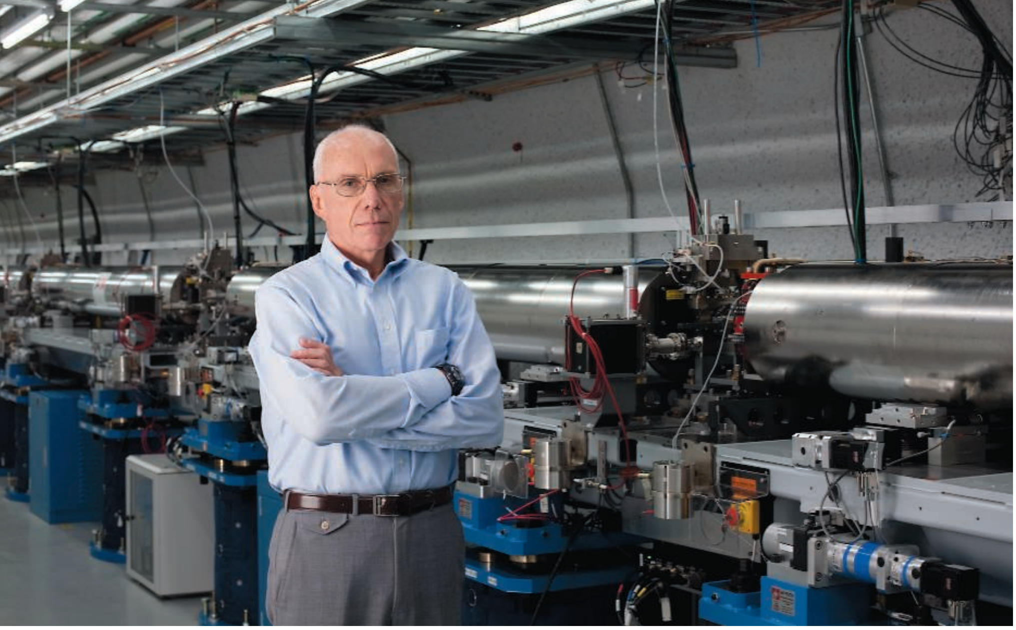
The LCLS wasn't always so attractive to scientists. The idea was dreamed up in 1992 by Claudio Pellegrini of the University of California, Los Angeles. He and SLAC's Herman Winick proposed a $100 million demonstration project that would work at slightly longer wavelengths. "All through the 1990s, it was just a curiosity," Winick says. "DOE didn't really want to hear about it because they were busy with the [synchrotron] sources."

Even as plans evolved for shorter wavelengths, x-ray scientists remained wary. "Many of us weren't quite sure what we would do with such a machine," Stöhr says. Various independent reviews convinced DOE that the LCLS was worth pursuing—although it insisted on a larger, potentially expandable facility, raising the cost to $420 million.

Drell's predecessor, Jonathan Dorfan, targeted the LCLS as the lab's next major facility, but some SLAC scientists were reluctant to get involved in the project. From 1999 until 2008, most lab researchers focused on running an electron-positron collider called PEP-II and the accompanying BaBar particle detector, which measured particles called B mesons to probe the asymmetry between matter and antimatter. Some people had to be ordered to work on the new project, says Tor Raubenheimer, director of accelerator research at the lab.

At the same time, DOE wanted SLAC to improve its outmoded management structure and practices. Drell made it her mission to push the hesitant lab down the path ahead of it.

CREDIT: DIANA ROGERS/SLAC



In a flash. SLAC's John Galayda directed construction of the world's first x-ray laser. The machine came on in less than 2 hours and immediately met or exceeded its design goals.

CREDIT: BRADLEY R. PLUMMER/SLAC

SLAC had traditionally promoted from within, choosing managers from among its scientists. Drell hired outside experts in management for positions such as chief operating officer and director of environment, safety, and health. SLAC needed the perspective of newcomers with more professional management experience, she says.

Drell herself hardly fits that description, however. The daughter of Sidney Drell, a prominent particle theorist at SLAC, she had been a professor at Cornell University when she joined SLAC in 2002 as director of research. It was her first foray into management at a national lab. "Granted, she didn't have all the experience, but she had all the right instincts," says William Madia, Stanford's vice president for SLAC, who has been director of two national labs himself.

Drell reorganized the lab to try to break down barriers between the particle physics and x-ray science sides of the lab, for example, by pulling all accelerator work into its own division. She instituted protocols that in 2 years reduced SLAC's accident rate, which had been twice the industrial average, by 67%. (She also formed a committee to rename the lab when DOE and Stanford got into a spat over rights to the old name, Stanford Linear Accelerator Center.)

Drell says she's committed to doing what's best for the scientific community as whole, even if it means taking a hit at home. In December 2007, last-minute cuts to the federal budget forced the lab to lay off 100 of its then-1600 staff. Drell simply made the cuts. In contrast, officials at Fermilab delayed similar layoffs until the U.S. Congress came to the rescue with extra money. The crisis forced DOE to scuttle the PEP-II collider 6 months early, another decision Drell did not fight, to keep Fermilab's larger Tevatron Collider running. "DOE's Office of High Energy Physics had to make some tough decisions, and I supported those decisions," Drell says.

That rankled many physicists, who thought Drell should have already been fighting to push back PEP-II's scheduled shutdown by a couple years. "I thought Persis should say to the DOE, 'Straighten out our particle physics program, or I'm going to resign,'" says Martin Perl, another of SLAC's Nobelists.

Now that SLAC has started to come through its transition, however, some critics have begun to warm to Drell's vision and style. Perl says he now realizes that lab directors no longer have the kind of power they used to and that what Drell did was best for SLAC. "A few months ago I apologized to her," he says. "I was wrong."

Dreams deferred

SLAC has not given up on particle physics, although it has expanded its conception of the field to include astrophysics. For example, SLAC researchers helped build the main instrument for the Fermi Gamma-ray Space Telescope, launched in June, and run the operations center that processes its data. Some SLAC physicists are joining in experiments at Europe's Large Hadron Collider (LHC) near Geneva, Switzerland, which should start smashing protons this winter. Some are still analyzing data from BaBar.

That's a far cry from physicists' ambitions of just a few years ago. Throughout the 1990s, SLAC researchers developed plans for a linear collider 30 kilometers long and based on the same basic technology as its linac. Dorfan says they hoped that, by about 2010, SLAC would lead a global effort to build the machine, which would complement the LHC. In 2004, however, the particle-physics community opted for a different technology being developed primarily in Germany. In 2007, DOE lost enthusiasm for the whole project, when physicists estimated the cost at well over $7 billion.

Some physicists say that SLAC could do more to maintain an accelerator-based particle physics program. The PEP-II collider could be upgraded to boost its collision rate, an option SLAC shelved to push for the linear collider, says lab veteran David Leith. In fact, researchers in Italy would like to rebuild the machine at the University of Rome Tor Vergata. "I'm working very hard to have this as part of the lab's program," Leith says, "but it doesn't seem to fit into the new direction." Without such a project for researchers to work on, SLAC's expertise in electron accelerators—its *raison d'être*—will likely wither, Leith says.

Others say that in the transition to a multipurpose lab, SLAC has lost the cohesive culture that made it such a stimulating place to work. Michael Huffer, who worked on the BaBar particle detector, says SLAC's ethos reflected the values of its founding director, Wolfgang Panofsky: Everyone from the scientists to the custodians should have a say, there should be little hierarchy, and the lab should maintain its independence.

Now the lab is more bureaucratic, and DOE takes a bigger role in its inner workings, Huffer says. DOE site officials now roam the site to talk directly to employees, he says, something he doubts Panofsky or Richter would have tolerated on the grounds that Stanford alone ran the lab. "Management has to worry that the things that made SLAC attractive to people are the things that aren't here anymore," Huffer says. "If you kill that culture, you kill the golden goose."

Still, most scientists are adjusting. Christopher O'Grady also worked on BaBar and says he would have been happy if SLAC's particle physics experiments had continued. But even as it became clear that they wouldn't, O'Grady says, he was becoming intrigued by something else entirely: the basic science needed to address the world's energy problem.

So O'Grady, 45, signed on to work on LCLS experiments, which are likely to be more relevant to the issue. "Just this morning I was in a meeting with the catalyst guys, and it was pretty challenging because I don't know what's going on," he says. O'Grady says he has no regrets, though. "I decided in the eighth grade that I wanted to do high-energy physics, and that's what I did. This is the first time in my life that I've ever wanted to do something else." At SLAC, now is the time to make a change. **–ADRIAN CHO**

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