

Accelerator Labs Regroup as Photon Science Surges

X-ray free-electron lasers signal a culture change at two accelerator labs—and offer them a new lease on life.

“We have an enormously exciting new territory we are going to pursue. It has discovery potential and science potential written all over it,” says Jonathan Dorfman, speaking of the x-ray free-electron laser (XFEL) to be built at SLAC, where he is director. The German Electron Synchrotron laboratory (DESY) in Hamburg and RIKEN’s Harima Institute in Japan have similar projects in the works.

They differ in detail, but the trio of upcoming large-scale XFELs will produce coherent, intense, ultrafast pulses of hard x rays. The pulses will be on the time and wavelength scales of molecular and atomic processes, and have 10 billion times higher peak brightness than synchrotron radiation sources. Keith Hodgson, SLAC synchrotron director, says moving from a synchrotron source to an XFEL—sometimes called a fourth-generation x-ray radiation source—is a much bigger step than was “going from x-ray tubes in one’s own lab to a synchrotron light source.” Adds John Galayda, project director for the Linac Coherent

Laser Source (LCLS), SLAC’s XFEL, “Everyone says the important stuff is unimaginable at this time.”

But alongside the buzz of excitement surrounding the XFELs are fears that particle physics will get short shrift. Not only are SLAC and DESY shifting their energies from their traditional strengths in particle physics to photon science, but particle physicists will be biting their nails until they’re sure that the international linear collider (ILC) they’re banking on will actually be built.

Evolution and revolution

In terms of technology, developing the XFELs is widely viewed as a natural evolution for SLAC and DESY. “I was surprised to see how similar the strategies of the two labs are,” says DESY

director Albrecht Wagner. “We both profit from the coexistence of accelerators and x-ray light sources. The major breakthroughs to the x-ray free-electron laser are only [made] possible by the accelerator R&D, which has been driven by particle physics.”

As for expected scientific payoff, the new XFELs will be “a unique approach to ultrafast science,” Dorfman says. “We will be able to image objects at atomic scales and get moving pictures of chemistry and biology in real time. The gains in intensity and shortening in pulse duration will cause a revolution in x-ray science.”

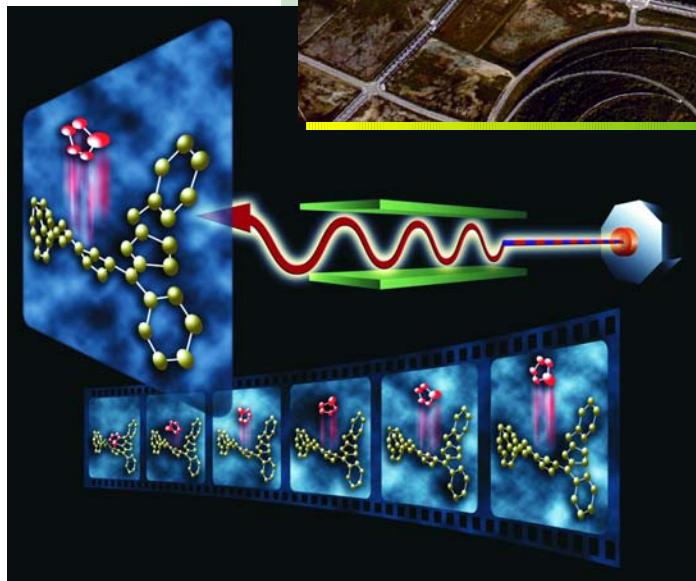
Research envisioned for the XFELs encompasses everything fast and small. At all three facilities, the wavelengths will be in the angstrom range, pulses will provide 10^{12} photons, and the pulse lengths will start out on the order of 100–200 fs and later be shortened (see table). Says Galayda, “In that short a time, there is no blurring of the positions of atoms as a result of motion.”

Imaging single molecules

(lower left) is one application that scientists are looking forward to with x-ray free-electron lasers. Construction is under way on a US facility; prototype undulators (lower right) for Europe’s facility are being tested; and, pending approval, Japan plans to build an XFEL (left, in green) next to SPring-8, the country’s third-generation synchrotron source. (Cartoon courtesy of SLAC.)



RIKEN/HARIMA



DESY/HAMBURG

X-Ray Free-Electron Laser Projected Parameters

	LCLS (US)	DESY XFEL (Europe)	SCSS (Japan)
Pulse duration	<230 fs	100 fs	80 fs
Wavelength	1–64 Å	1–15 Å	1–50 Å
Repetition rate	120 Hz	10 Hz	60 Hz
Electron bunches per pulse	1	≤3000	1
Electron beam energy	4–14 GeV	≤20 GeV	≤8 GeV
Photons per pulse ($\times 10^{12}$)	1.2 (at 1.5 Å)	1.2 (at 1 Å)	0.76 (at 1 Å)
Linac length	1 km	2 km	350 m
Estimated cost*	\$379 million	\$1 billion	\$330 million
Estimated start date	2009	2012	2010

*Estimates include varying amounts of instrumentation and different methods of accounting.

The new facilities are expected to reveal details about the structure and dynamics of particles, individually and in small clusters—in atoms and molecules, in materials, and during chemical reactions. Says Jerry Hastings, spokesman for the Sub-Picosecond Pulse Source, an LCLS precursor, “You will be able to use a laser beam to initiate a change that has motions on the atomic scale, and [use] x rays for scattering to determine positions at some later time—kind of like time-lapse photography.” The XFELs are expected to be especially useful for studying proteins and other biomolecules that don’t crystallize and so can’t be probed by standard diffraction methods. And, says Galayda, “if you can get down to a femtosecond or perhaps below, you could think of observing electrons rearranging themselves in an atom.”

Another area of research is plasma physics. “Until now, the light sources were not particularly good for dynamic processes in the x-ray regime because they didn’t have enough oomph,” says Richard Lee of Lawrence Livermore National Laboratory. The LCLS, he says, “is tunable, intense enough to move plasma populations around, and fast enough to watch emissions. We will be able to study an incredibly large range of exotic states of high-energy-density matter. This affects everyone from astrophysicists who look at plasma spectra to the weapons guys.”

Multiprogram transition

The LCLS is first in line to turn on, in 2009. As its injector, it will use a third, or about 1 km, of SLAC’s linac. That saves several hundred million dollars, which leaves the estimated construction cost at \$379 million. President Bush’s budget request for fiscal year 2006 includes \$89 million for the

LCLS, up from \$54 million this year. “The linac has always been the basis of the laboratory,” says Dorfman. In its 40-year lifetime, the linac has done duty in a succession of accelerators. It’s currently the injector for the B factory, which will be turned off in 2008 to make way for the LCLS. SLAC, continues Dorfman, “has prided itself on innovation and on making large jumps in facilities with capacities for discovery.”

Another jump associated with the LCLS is the transfer of \$30 million in linac running costs within the US Department of Energy, from the Office of High Energy Physics to the Office of Basic Energy Sciences. “The next large user facility will be the LCLS, so it’s proper that the program that is supporting construction also be responsible for the operation,” says Robin Staffin, DOE associate director for high-energy physics. Dorfman adds that the “lab is transitioning from a primarily single-program to a multiprogram lab” and that, in the coming months, plans will be formulated for restructuring SLAC’s accounting and management systems.

Still, the shift within DOE came as a surprise, even to SLAC managers, and some people are unhappy about it. Where the money comes from “doesn’t make a difference for the users,” says veteran SLAC high-energy experimenter and Nobel laureate Martin Perl, “but it makes a difference for the people running the SLAC linear accelerator and dreaming about improving it. They will be thinking about getting better photon sources, rather than about getting better luminosities. I think we will see a slowing up and lack of invention in accelerator physics for high-energy physics.”

Cold technology synergy

At DESY, Wagner says, the emphasis on photon science is “absolutely not”

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an identity shift for the lab, but rather a “shifting [of] the weight from one leg to another.” Germany will pay roughly 60% of the projected C795 million (roughly \$1 billion) construction cost for the DESY XFEL. So far, nine other European countries have signed on for a planning phase: Denmark, France, Greece, Italy, Poland, Spain, Sweden, Switzerland, and the UK. By mid-2006, the partners aim to set forth details on the mode of collaboration, technical design, schedule, cost breakdown, and financing for the project. The DESY XFEL is scheduled to start up in 2012.

Like SLAC, DESY will close a high-energy physics facility in the lead-up to building its XFEL. In this case, it's the Hadron Electron Ring Accelerator (see PHYSICS TODAY, September 2003, page 27); about one-eighth of HERA's injector, PETRA, is to be converted into a state-of-the-art synchrotron radiation source. Closing HERA in 2007 will free up manpower and money—about C50 million, or a third of DESY's operations budget.

The DESY XFEL will use superconducting, or “cold,” RF cavities—the technology agreed upon internationally for the ILC (see PHYSICS TODAY, October 2004, page 34). “The synergy we get from doing one job for two projects is really enormous,” says Robert Klanner, who until recently was DESY research director. Another difference, related to the cold technology, is that the DESY XFEL will deliver pulses in bunches of 3000, with a repetition rate of 10 Hz; the LCLS and Japan's SCSS (SPRING-8 Compact SASE Source; SASE stands for self-amplified spontaneous emission) will initially produce single pulses with repetition rates of 120 Hz and 60 Hz, respectively.

Catching up

Japan made a late reentrance into the race for an XFEL, but its SCSS could open for experiments as early as 2010. The project was on hold when, early this year, the country's Ministry of Education, Culture, Sports, Science and Technology called for an international review. “To give you a flavor of the excitement,” says SLAC's Hastings, who served on the review panel, “the international review reported at 5pm on a Friday. The ministry called at 5:05 to find out how the review went. You wouldn't get that in the US.”

Size sets the SCSS apart. “Land cost is very, very high,” says project director Tetsuya Ishikawa, “so we cannot afford a very long accelerator.” To pack the needed punch into a linac only 350 m long—compared with

1 km for the LCLS and more than twice that for the DESY XFEL—the SCSS will use a high-gradient accelerator. Among the other tricks for keeping the SCSS compact is the placement of the undulator magnets inside the accelerator vacuum so that “shorter wavelengths are attainable with lower electron energies,” says Ishikawa. The SCSS will be built next to SPRING-8, a third-generation synchrotron light source 70 km west of Kobe. The estimated tab is \$250–330 million, depending on how many undulators are built.

Accelerator gap

With no major high-energy experiment on site at SLAC and DESY, says SLAC's Herman Winick, “the intellectual culture will become more and more photon science.” One change, adds Klanner, “will be in the external visitors. Instead of particle physicists coming for months, the foreign visitors for the XFEL will come for just a few days. This will have a big impact in the corridors, the canteen, and the laboratories.”

But managers at DESY and SLAC insist particle physics will remain strong at their labs. For starters, the XFELs themselves rely on accelerators. Says Dorfman, “The central jewel in SLAC's accelerator-based program will be the LCLS.” SLAC has a growing particle astrophysics effort, an area DESY is also strengthening. DESY also plans to join a high-energy experiment off site.

Most important, says Wagner, “the future of particle physics at DESY is the [international] linear collider, independent of where it is.” The same goes for SLAC, which is ruled out as a host site by tight space and earthquake vulnerability. “[The ILC] won't, of course, be built at the SLAC site,” says Dorfman. “But we are the only people who have built a linear collider. As the international community goes forward

and does the design, they couldn't do it without SLAC people.”

“For high-energy physics generally, as a community, the number of spigots is decreasing,” says Persis Drell, SLAC's associate director for research. “The field has made a choice. We have said the linear collider is our future. We have to accept some consequences. I'd much rather have the linear collider than a bunch of smaller machines—even one in my back yard.” Nervousness among particle physicists, she adds, comes from the uncertainty of change and “anxiety that the linear collider is not signed, sealed, and delivered. Sometimes you have to gamble for what you want.”

The gamble is whether countries will get money and agreements together to realize the ILC. In the meantime, in addition to the impending shutdowns at SLAC and DESY, Cornell University's electron-positron experiment is slated to turn off in 2008 (the experiment's storage ring will continue as an x-ray synchrotron source), and plans for Fermilab's BTeV experimental facility were dashed in February by President Bush's proposed budget for FY 2006. “The problem is the real scientific and financial cut of particle physics and the large gap in time until a new machine comes,” says Max Klein, spokesman for one of the HERA detectors.

Even particle physicists who oppose killing the smaller experiments back the ILC. And even those who, like SLAC experimenter Martin Breidenbach, see x-ray light sources as “parasites” that “have basically swallowed up SLAC and taken over the world,” admit that the XFELs mean SLAC and DESY are “extremely well positioned” to survive as institutions. Or, as DOE's Staffin puts it, “as a scientific facility, without an LCLS, it's not clear where SLAC would go at all. It's pretty creative.” **Toni Feder**

Nuclear Power Needs Government Incentives, Says Task Force

Citing economics, climate change, and the projected growth in global energy demand, a US Department of Energy (DOE) task force cochaired by former Nuclear Regulatory Commission (NRC) chairman Richard Meserve and former New Hampshire Governor John H. Sununu has recommended that the federal government help revitalize the US nuclear power industry by sharing the up-front costs

A high-profile US government task force says it is in the national interest to use nuclear power as a clean and increasingly economical way to meet the growing demand for electricity.

of the first few of a new generation of nuclear power plants. After citing three decades of increasing efficiency, decreasing operating costs, and solid