Status of the LCLS X-Ray FEL Program

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Abstract

The Linac Coherent Light Source (LCLS) program involves a collaboration of several US National Laboratories and universities with the goal of designing and building the first 4th-generation hard x-ray source, an x-ray free-electron laser (FEL). This FEL will utilize extremely short, intense, low-emittance electron pulses created by the high-energy linear accelerator at the Stanford Linear Accelerator Center. The FEL radiation produced will feature unprecedented peak brightness, short pulse length, and spatial coherence, tunable over an energy range of 0.8–8 keV. With favorable funding, major construction will begin by 2004 and the LCLS will be operating late in 2006. The LCLS facility will include experimental stations for carrying out groundbreaking experiments in several scientific fields. Current R&D efforts are directed at experimentally studying the physics of high-gain FELs, and refining the details of the plan for the LCLS facility. The FEL experiments, at Argonne and Brookhaven National Labs (along with experiments carried out at the German laboratory DESY), have confirmed the basic physical concepts upon which LCLS is based, and have demonstrated that many of the stringent technical requirements can already be met.

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INTRODUCTION: THE LCLS PROJECT

A free-electron laser (FEL) is a device for producing coherent radiation from a high-energy electron beam [1]. It has some similarity to an undulator source of synchrotron radiation, but whereas undulator radiation derives from electrons that are randomly spaced (on a scale of the radiation wavelength) the FEL incorporates a mechanism for longitudinal bunching of the electrons with the same period as the radiation (microbunching), so that the radiation emitted by the electrons is coherent [2]. The microbunching is driven by the radiation field itself, bathing the electrons as they move through the undulator at relativistic speed. In order for the microbunching to be effective, the electrons and radiation field must couple well. In particular, the emittance of the electron beam must match the emittance of the diffraction-limited coherent radiation field. This condition can be achieved for micrometer-wavelength radiation using electrons in a low-emittance storage ring [3], but even the large third-generation light source rings cannot support FEL action at x-ray wavelengths.

It is possible in principle to achieve the necessary conditions for an x-ray FEL using a high-energy linear electron accelerator. In 1992 it was first pointed out that the linear accelerator at the Stanford Linear Accelerator Center (SLAC) should be capable of driving an x-ray FEL [4]. Interest in this idea has grown, and has resulted in a project called the Linac Coherent Light Source (LCLS).

The LCLS will utilize one third of the 3-km SLAC linac to accelerate an extremely bright electron pulse. During a single pass through a long (100m) undulator, this pulse will initiate FEL action at the undulator fundamental wavelength, which will be tunable between 15 Å and 1.5 Å. The FEL will operate in Self-Amplified Spontaneous Emission (SASE) mode, meaning that the FEL radiation field will arise from amplification of the spontaneous undulator radiation created at the start of the long undulator. Figures 1 and 2 illustrate the current conception of the LCLS. An extensive description of the proposed machine can be found in the LCLS Design Study Report, prepared in 1998 [5].

FIGURES

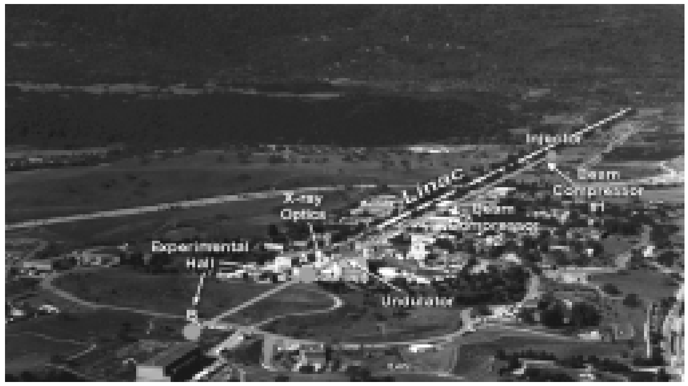

FIG. 1. Photograph of the SLAC site showing proposed placement of the LCLS.

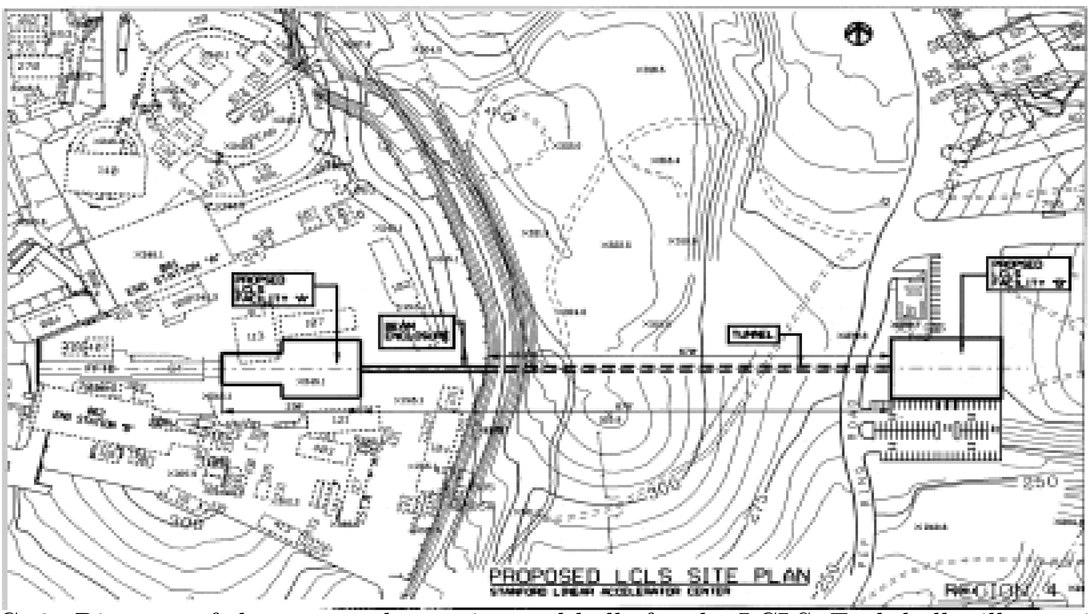

FIG. 2. Diagram of the proposed experimental halls for the LCLS. Each hall will contain four or five sequential experimental stations. All of the stations in both halls share a single FEL source, so only one station will be active at a time.

Due to the extremely short and bright electron pulse, and due to the exponential FEL amplification, the radiation produced by the LCLS will have unique properties. Its peak brightness will be about ten orders of magnitude greater than that of a third-generation synchrotron light source, its pulse length will be about three orders of magnitude shorter, and it will exhibit complete spatial coherence. These properties offer unprecedented opportunities is many fields of science [6].

Since the publication of the Design Study Report, the LCLS project has grown and become more formalized. It is now generally recognized as the most exciting possibility for a new x-ray source, and there is high expectation that construction funding will materialize within the next few years [7,8]. This paper summarizes the current status of the project.

ORGANIZATION OF THE LCLS PROJECT

The LCLS project involves formal participation from six institutions (SLAC, Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and the University of California Los Angeles) and informal collaboration with individual scientists from a number of other facilities. The Project Director is John Galayda of SLAC. Some of the participating institutions have taken on responsibility for particular aspects of the project. For instance, Argonne will develop the long LCLS undulator, and LLNL will develop the x-ray optics.

Two external advisory committees were formed in 1999 to assist in the LCLS planning process. The Technical Advisory Committee (TAC), chaired by W. Colson of the Naval Postgraduate School, considers questions of technical feasibility and strategies for assuring successful operation of the LCLS. The Scientific Advisory Committee (SAC), chaired by J. Stöhr of SLAC and G. Shenoy of Argonne, considers the potential scientific applications of LCLS.

While a detailed budget for construction of the LCLS has not yet been finalized, the total cost is expected to be about $200M. Construction is expected to take three years, and could begin in the fall of 2003. First light would be expected in 2006.

RECENT DEVELOPMENTS

During the past year the LCLS project has achieved significant progress in both administrative and technical areas. Most important was the endorsement given to the LCLS program by the Basic Energy Sciences Advisory Committee (BESAC) of the Department of Energy (DOE). In order to evaluate the LCLS scientific impact, BESAC asked the LCLS SAC to develop detailed concepts for a few initial experiments to be carried out at LCLS. Five such experiments were presented to the committee in October 2000. These experiments [9] cover a range of scientific disciplines from atomic physics through plasma physics and chemistry to materials science and biology. The experiments and the new scientific capability they indicate were strongly endorsed by the committee. This convinced DOE of the need for the LCLS facility. In June 2001, James Decker, Principal Deputy Director of the DOE Office of Science, signed a Critical Decision 0 document, identifying the LCLS project as "a unique opportunity for a major advance in carrying out" the mission of the Office of Science.

Meanwhile, DOE has been funding R&D related to LCLS since 1999 at a level of about \$1.5M per year. This funding, and additional funds contributed by the LCLS institutions, supports such activities as the development of a high-brightness photocathode electron gun at SLAC, the construction of a prototype LCLS undulator at Argonne, and the development of precision x-ray optics at LLNL.

There have also been two recent successful SASE FEL experiments by the LCLS collaboration. In the fall of 2000, the Low-Energy Undulator Test Line (LEUTL) experiment at Argonne achieved SASE amplification to saturation at wavelengths as short as 390nm [10]. Then, in the spring of 2001, the Visible to Infrared SASE Amplifier (VISA) experiment at Brookhaven achieved saturation at 830nm [11], and demonstrated the ability to accelerate electron pulses that meet the emittance requirements of LCLS. The results of both experiments agree very well with SASE FEL theory, giving high confidence that the design parameters of LCLS have been properly chosen [12].

CONCLUSION: WHAT'S NEXT?

The next step toward the realization of an x-ray free electron laser will be the submission of a Conceptual Design Report (CDR) to DOE during the winter of 2002. A favorable review of the CDR will pave the way for major project funding. This should lead to an operating LCLS, the first fourth-generation light source, within the next five years.

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[11] See `http://www-ssrl.slac.stanford.edu/VISA/`

[12] Very recently, the SASE FEL experiment at the German accelerator laboratory DESY has also achieved amplification to saturation, at a wavelength of 98nm. See `http://tesla.desy.de/new_pages/6120_Annoucements.html`