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THE LINAC COHERENT LIGHT SOURCE-II PROJECT*

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Abstract

The "Linac Coherent Light Source–II" Project, initiated in September 2010, has gone through a radical transformation beginning in August 2013. In its new form, LCLS-II will construct a 4 GeV CW superconducting linac in the first kilometre of the existing linac tunnel. A new undulator, optimized as a soft x-ray (200-1,300 eV) source, will receive electrons from the new SC linac. The existing undulator system will be replaced with a new variable gap device, which will receive electrons from either the new SC linac (providing 1-5 keV photons) or the copper linac presently used by LCLS (providing 1-25 keV x-rays). First light from the new facility is expected in September 2019.

TRANSFORMATION OF LCLS-II

In May 2009, one month after Linac Coherent Light Source produced first x-rays, SLAC began the development of a concept for LCLS-II, an expansion of the facility. This concept was reviewed and approved by the Department of Energy in October 2011. Turmoil in the Congressional budget approval process 2011-2013 prevented the start of LCLS-II construction as originally proposed. Meanwhile the DOE Office of Basic Energy Sciences initiated a re-assessment [1] of its science priorities and plans for new facilities in order to make the best of budget constraints. It was necessary for the LCLS-II concept to undergo a radical transformation to properly respond to the conclusions of this reassessment. The transformation is now well underway. A concept [2] for the transformed LCLS-II has been presented to DOE, and has received favourable review. Formal approval of the concept is expected in the next few months. Construction of the new concept could be completed by late 2019, if funding is sufficient to support fast progress.

THE LCLS-II COLLABORATION

The rapid transformation of LCLS-II has been possible only because several *US laboratories have joined in a collaboration to* design and construc*t this facility.* Thomas Jefferson National Accelerator *Facility (*JLAB), Fermi National Accelerator Laboratory (FNAL), Argonne National Laboratory (ANL) *and Cornell University* have joined *SLAC and* Lawrence Ber*keley National Laboratory (*SLAC's collaborator in the original LCLS-II*)* to develop the new concept and to construct the facility.

LCLS-II PROJECT GOALS

The DOE re-assessment stated that "it is considered essential that the new light source have the pulse characteristics and high repetition rate necessary to carry out a broad range of coherent "pump probe" experiments, in addition to a sufficiently broad photon energy range (at least ~0.2 keV to ~5.0 keV)." This statement became a requirement: LCLS-II must provide a continuous (CW) stream of equally-spaced x-ray pulses at high repetition rate to multiple undulators, covering a spectral range 200eV-5keV.

Based on input from x-ray experimenters and optics experts, the LCLS-II goals for its high repetition rate x-ray sources include delivery of least 20W average power to its experiment stations.

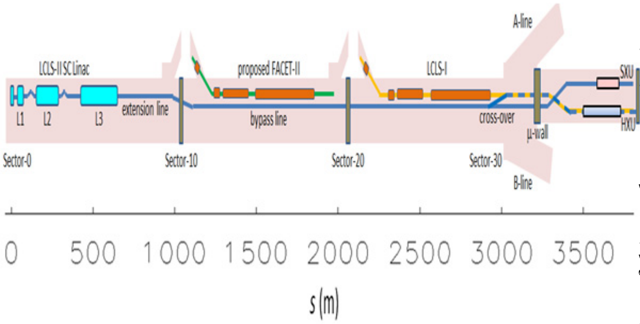

Figure 1: Layout of LCLS-II accelerators and undulators.

Most of the experiments done at high repetition rate will demand the best possible control (or, alternatively, measurement) of time delay between pump laser and x-ray probe. Shot-by-shot timing data can be used to sort shot-by-shot frames of pump/probe data with few-femtosecond precision or better [3]. For experiments designed to integrate signals from many shots, time resolution will be limited by timing jitter during the integration time. Jitter has been reduced to 20fs or less at FLASH [4], and much effort will be invested worldwide to achieve further improvements. For now, the LCLS-II design goal for LCLS-II will be <20 fs jitter.

LCLS-II will provide nearly "transform limited" pulses by means of self-seeding. It is expected that this will be done by re-installing the systems already tested successfully [5, 6] at LCLS, with after some modification.

Pulse duration together with timing stability, constitute a research frontier; improvements (meaning shorter pulses and commensurately stable timing) in these parameters enable new science at FELs. Design goals for LCLS-II pulse durations are 2-300 fs. Shorter pulses would be very desirable, however, and both the LCLS facility and the LCLS-II project will continue to seek means of producing shorter pulses. Table 1 summarizes the target electron beam performance parameters of the new SC linac. The copper linac will not be modified by LCLS-II.

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LCLS-II DESIGN

Basic Goals for the Transformed LCLS-II

LCLS-II will replace a portion of the existing SLAC linac with a 4 GeV superconducting linac. This linac will be installed 2 km upstream of the LCLS copper (Cu) linac, which will continue to be used for LCLS operation when LCLS-II is completed. The SC linac will be designed to provide pulses of electrons at up to ~1 MHz, to be distributed to two new variable-gap undulator systems installed in the existing LCLS undulator hall. The new soft x-ray (SXR) undulator will cover the spectral range 200-1,300 eV. The existing fixed-gap undulator will be replaced with a new variable gap hard x-ray (HXR) undulator, tunable over the range 1-5 keV with electrons from the SC linac.

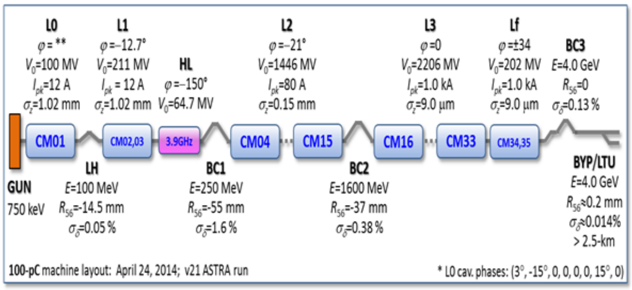

Figure 2: Schematic of LCLS-II accelerator. “LH” signifies a laser heater system intended to control CSR instability. “CM” is the prefix nomenclature for the 35 ILC/XFEL design cryomodules.

Table 1: LCLS-II Electron Beam Parameters

Parameter	**Nominal**	**Range**	**Units**
Final electron energy	4	2-4.14	GeV
Electron bunch charge	0.1	0.01-0.3	nC
Bunch repetition rate	0.62	0-0.93	MHz
Average linac current	62	1-300	µA
Average beam power	0.25	≤1.2	MW
emittance	0.45	0.2-0.7	µm
Peak current	1	0.5-1.5	kA
Bunch length	8.3	0.6-52	µm
Usable bunch length	50		%
Compression factor	85	25-150	
Slice energy spread	0.5	0.15-1.5	MeV
Beam stability goals			
Energy, rms	<0.01		%
Peak Current	<5		%
Bunch arrival time	<20		fs
beam stability (x, y)	<10		%

SC Linac: Electron Beam Power

The LCLS-II SC linac will be designed to ultimately accelerate 300 microamperes at 4 GeV. It is anticipated that LCLS-II performance goals can be met and indeed exceeded with 30 microamperes delivered to a single undulator. Electrons emerging from the undulators will be directed to new beam dumps [7], each designed to handle a 120 kW electron beam.

Injector

The electron gun envisioned for LCLS-II is based on the gun developed for the NGLS project and now being tested in prototype form [8] at Lawrence Berkeley National Lab. The Cornell Energy Recovery Linac DC gun design [9] is also being considered. Cornell and LCLS-II are making plans for tests of the DC gun to further investigate its suitability for LCLS-II. Both guns can deliver the necessary charge at high repetition rate; however their output electrons are sufficiently different in energy to require different capture/compression schemes. A multi-objective optimization [10] of the LBNL injector for 20pC, 100pC and 300pC charges indicates that slice emittances of 0.2- 0.6 mm-mr can be achieved at 98 MeV.

Linear Accelerator

The 4 GeV linear accelerator will include 35 cryomodules, each containing eight 1.3 GHz 9-cell cavities, the design of which will be based heavily on the TESLA/ILC/XFEL designs, modified to support CW operation [11]. A cryomodule containing 3.9 GHz cavities will be installed to shape the longitudinal phase space of the electron bunch. Liquid helium for the linac will be provided by a cryogenic refrigeration plant to be installed approximately 500m from the upstream end of the new linac. It will have 4 kW cooling capacity at 2^{o}K.

Electron Beam Transport and Distribution

As shown in Figure 1, electrons from the new linac will be transported 1 km to Sector 10 where they will be deflected upward to a bypass transport line mounted on the ceiling of the linac tunnel. The electrons will travel past all intervening copper linac systems, including the existing LCLS linac, to the Beam Switchyard area. A fast deflector system will distribute electron bunches to one or both undulator systems in the existing LCLS Undulator Hall, with some bunches extracted to a tune-up diagnostic dump. The overall electron optics layout for LCLS-II is described elsewhere in these proceedings [12]. It is envisioned that fan-out of the electron bunches to the two undulator beam paths will be accomplished by a superconducting RF deflector [13]. A pulsed fast kicker is also being investigated as an alternative.

High Q_o Cavities

The LCLS-II will linac will make use of 1.3 GHz 9-cell cavities that will be treated by the nitrogen doping process developed at FNAL [14]. An extensive testing program is underway at FNAL, JLAB and Cornell to characterize and standardize the doping process so that it can be implemented by commercial manufacturers. Performance goals for LCLS-II cryomodules include a target operating gradient of 16 MV/m and an average unloaded Q_o of 2.7×10^{10} at a temperature of 2K. Results of vertical tests of 9-cell cavities have demonstrated that these performance targets can be surpassed by a significant margin. With this performance from the RF cavities, the cryoplant design developed by JLAB for the Facility for Rare Isotope Beams (FRIB) can be adapted to LCLS-II.

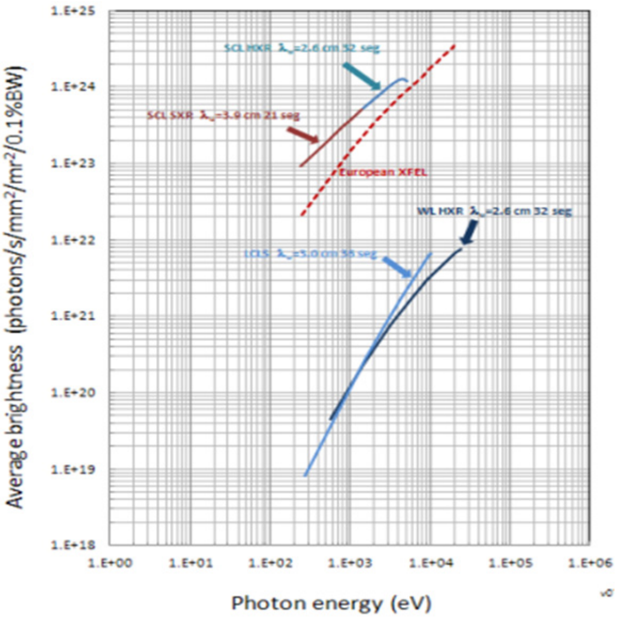

Figure 3: Average brightness of LCLS-II x-ray sources. The two-color line shows the new sources fed from the SC linac. The *light* & dark blue line*s show* the *existing vs.* new hard x-ray source*s* fed from the copper linac.

X-Ray Sources

The existing LCLS undulator hall was designed to accommodate two x-ray sources. The new dedicated SXR source will contain 21 undulators, each with period 39mm and length 3.4m segments. The replacement hard x-ray source will have 32 undulators with period 26mm. The expected average brightness of these sources is shown in Figure 3. When fed by the copper linac, the shortened period of the HXR source trades slightly reduced brightness below 10 keV in exchange for extension of the tuning range up to 25 keV.

Downstream of the electron beam dumps, new x-ray attenuators, collimators, mirrors and operations diagnostics must be installed. Additional upgraded collimators will be required to deliver x-rays to upgraded versions of the existing instruments.

ACKNOWLEDGEMENT

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