LCLS II DESIGN

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Abstract:

A one-day workshop was held on July 21st, 1998 to consider upgrade paths to the existing LCLS design with a view to making a facility with multiple FEL and spontaneous synchrotron radiation beamlines. The agenda, working groups and participants in this workshop are listed in Appendix 1. This technical note summarizes the ideas generated by this workshop.

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1. Introduction

A one-day workshop was held on July 21st, 1998 to consider upgrade paths to the existing LCLS design. The agenda, working groups and participants in this workshop are listed in Appendix 1. This "white paper" summarizes the ideas generated by this workshop.

The present LCLS design, LCLS-I [1], may be thought of as an "existence proof" user facility in that it accelerates single bunches of electrons, passes them through a single undulator and has a limited number of x-ray beamlines to exploit the physics possibilities. Progression to a full-fledged 4th generation x-ray light source will require extending the design to have multiple electron beamlines feeding undulators. The radiation output of these undulators will in turn feed multiple optical beamlines thereby providing a facility that can support tens of experiments. To this end a very preliminary design for an upgrade to the LCLS has been started to explore the possibilities of more bunches in the linac, multiple electron beamlines, more x-ray beamlines, innovative SASE physics, more detailed x-ray physics R&D plans and better physical layouts of the experimental areas. This design, dubbed LCLS-II, is presented in nominal outline in this document. Of course more work will need to be done to optimize the various subsystems and parameters to obtain an actual design.

It should be emphasized that in order to prepare for the LCLS-II SASE FEL facility, LCLS-I will provide a unique and invaluable tool to address various R&D issues. In particular, aspects of beam switching will be studied, in preparation for a multiple-user facility. FEL seeding at x-ray wavelengths will be studied, in order to provide more control over the FEL spectral/time structure. X-ray optics will be developed to meet the extremely precise requirements needed to fully utilize the coherence aspects of the FEL beam. Energy chirping will be studied, with a view toward producing very short (sub-fs) x-ray pulses. And pioneering x-ray FEL experiments will be done, developing new applications and leading the way toward forming the user community that will exploit the full capability of the LCLS-II user facility.

2. Layout

In order to move beyond the LCLS-I design to a fully functional short-wavelength FEL user facility, there are three major areas in which development will be needed. The first concerns the number of users that can be accommodated by the facility, the second concerns the spectral range covered, and the third concerns the details of the spectral/temporal quality of the FEL radiation.

An effective user facility will require a sizable technical infrastructure to maintain reliable, high-quality radiation production as well as to provide proper support for extremely complex experiments. The scientific productivity of the facility must be commensurate with this level of operational infrastructure, which means that a sizeable number of users must be accommodated. This requirement (and the spectral range and radiation quality issues discussed below) ultimately leads to the need for the facility to contain multiple experimental stations which can be used simultaneously. Given the very high cost of a high-energy linac and the moderately high cost of a long FEL undulator, this multiplicity can be most economically realized by using a single linac to feed several undulators, each of which can produce radiation for several experimental areas. In the scenario described in this paper, the linac feeds four undulators. The radiation output of each undulator can, through various optical schemes, serve four experimental stations leading to a facility with sixteen experimental stations. The facility is additionally enhanced by a number of smaller undulators producing spontaneous radiation (as opposed to FEL radiation). Though much less intense than FEL radiation, this spontaneous radiation is quite useful scientifically due to its ultra-short pulse length and extended spectral range into the very high region (>1 MeV). These spontaneous undulators make use of the "spent", but still good quality, electron beams from the outputs of the FEL undulators. The spent beams are highly correlated and bunched at the optical frequency and will have to be de-bunched and de-correlated before being used to make spontaneous radiation.

Figure 1 shows the proposed layout of the LCLS-II. The basic layout extends the present LCLS-I design. The injector and linac have the same layout but will accelerate a pulse train of electrons. The Undulator Hall (the present FFTB enclosure) will have multiple particle beamlines – the linac pulse train will be separated using RF separators - each with its own undulator. The undulators will be "stacked" in such a way that the resulting FEL radiation can be enclosed within a 1-meter diameter pipe. Immediately after the Undulator hall, there is the Spontaneous Radiation Experimental Hall. In this hall the spent electron beams from the undulators, which are still relatively high quality beams, will be passed through series of short undulators and will form the basis of many spontaneous radiation beamlines. The FEL radiation will pass through an evacuated beampipe, X-Ray Transport Line I, to a Near Coherent Radiation Experimental Hall, which will have beamlines for the high power FEL beams. The FEL beam can further drift through a second evacuated beampipe, X-Ray Transport Line II, to the Far Coherent Radiation Experimental Hall where there are further high power FEL beamlines. An overview of this layout on the SLAC site is shown in Figure 2.

The major LCLS-II accelerator parameters are compared with LCLS-I parameters in Table 1. Table 2 shows the optical radiation parameters for the longest and shortest wavelengths for the LCLS-II electron energy range. As one can see, the micropulse beam parameters are essentially the same in LCLS-I, but more bunches per pulse will be accelerated and the extracted beam bunches will be sent into four different beamlines using RF separators running at L-band. Each beamline will have its own undulator (the four undulators may be different) and the radiation output from each beamline will be split four ways to generate a total of 16 coherent radiation beamlines. In addition the spent beams from the undulators will be further used to generate 16 additional spontaneous radiation beamlines before being dumped. The 32 radiation beamlines so generated will be the basis of the nominal LCLS-II facility. Of course once the techniques for separating the electron and FEL radiation are developed, adding more beamlines and experimental stations can further enhance the facility. It should be noted that the nominal design for the number of bunches accelerated per pulse is 40 with a separation of 8.75 ns. This is considered to be relatively straightforward. It may be possible to increase this to 112 pulses with a separation of 3.25 ns but this has severe constraints for the Gun Laser, Gun and linac beam loading requirements.

Parameter	*Units*	*LCLS-I*	*LCLS-II*
Linac Beam Energy	GeV	5-15	2 – 15
Macro-Pulse Length	nsec	n/a	350
Macro-Pulse Rate	Hz	120	120
Linac Micro-Pulses/Macro-Pulse		1	40
Linac Micro-Pulse Spacing	nsec	n/a	8.754
Linac Micro-Pulse Spacing	s-band buckets	n/a	25
Number of Extraction Beamlines		1	4
Beamline Micro-Pulses/Macro-Pulse		1	10
Micro-Pulse Intensity	nC	1	1
Micro-Pulse Bunch Length	μm,RMS	20	20
Micro-Pulse Emittance	π mm-mrad	1.5	1.5
# of Spontaneous Radiation Beams		0	16
# of FEL Radiation Beamlines		2	16
Wavelength Range	Å	1.5-15	0.5-77

Table 1: Major LCLS-I and LCLS-II Beam Parameters

Parameter	*Units*	*2 GeV*	*15 GeV*
Peak 1st harm. FEL power	GW	11	9
Energy per FEL micropulse	mJ	2.6	2.2
Number of photons/FEL micropulse	10^{12}	72	1.2
FEL mode source size (FWHM)	μm	117	107
FEL mode source div. (FWHM)	μrad	63	1.3
1st harm, FEL Raleigh waste (rms)	μm	34	31
1st harm. FEL Raleigh Length	m	0.9	40
1st harm. Homogeneous bandwidth	%	0.03	0.03
1st harm. Inhomogeneous bandwidth	%	0.4	0.2
Peak 1st FEL harm. Power density (@10m)	10^{11} W/mm^2	0.3	8
Peak 1st FEL harm. Field (@10 m)	10^{10} V/m	0.5	2.5
Peak Brightness	10^{32} *	0.12	12
Average Brightness/undulator	10^{23} *	0.064	4.2
Peak Spontaneous Power	GW	1.6	81
Time-averaged spontaneous power	W	1.8	90
Source Size of Spontaneous Radiation (FWHM)	μm	117	82
Divergence of Spontaneous Radiation (FWHM)	μrad	63	4.9
Wavelength (first harmonic)	Å	77	1.5
Macro-Pulse rep rate	Hz	120	120
Micro-Pulse rep rate per undulator	Hz	1200	1200
Pulse train length	ns	350	350
Micro-Pulse duration (FWHM)	fs	232	232
Beta-Function	m	3	18
Electron Energy	GeV	2	14.35
Normalized Electron Emittance	π mm-mrad	1.5	1.5

* Photons/s/mm^2/mrad^2/0.1%BW

Table 2: Optical Parameters For The Longest & Shortest LCLS-II Parameters

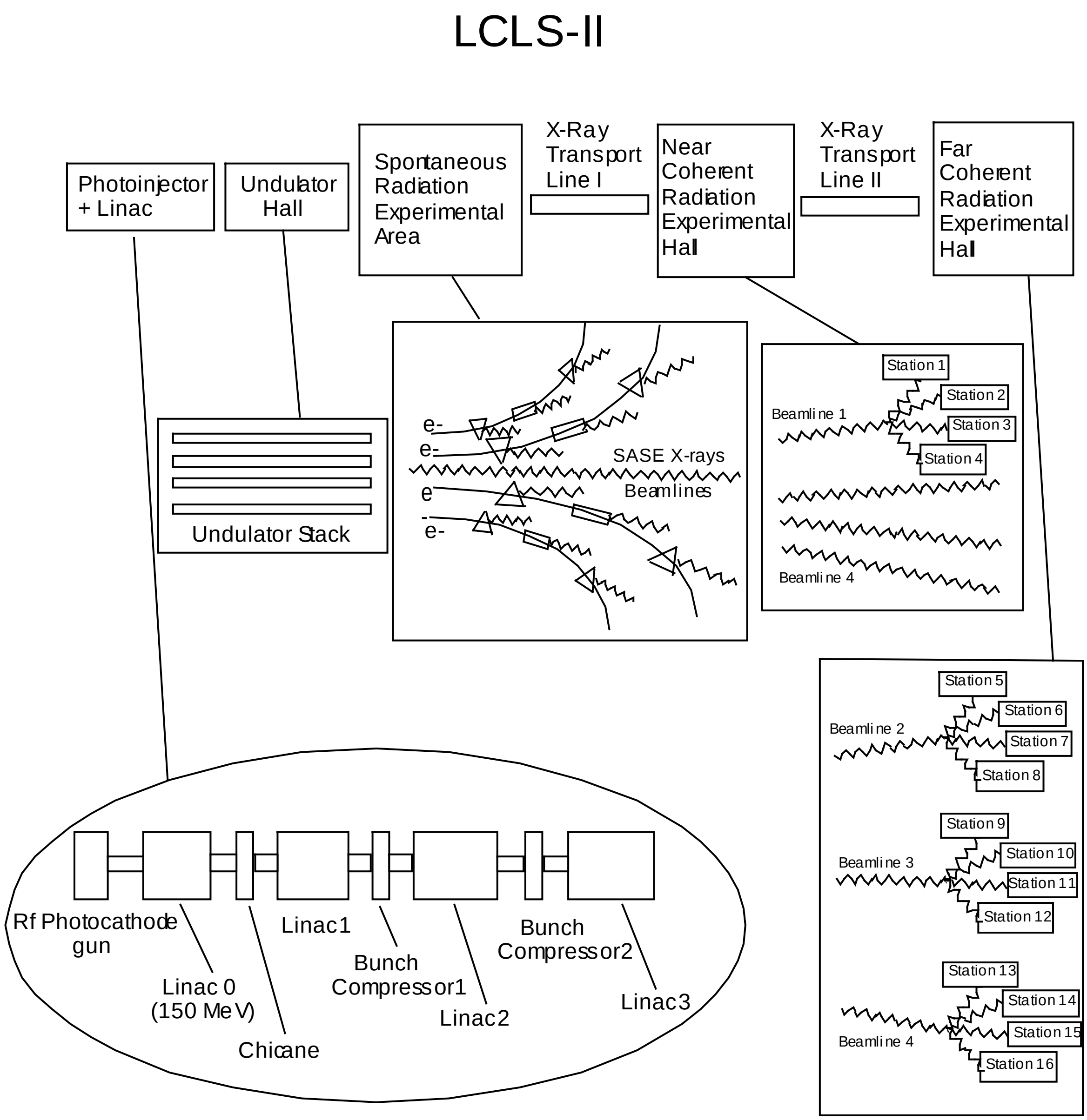
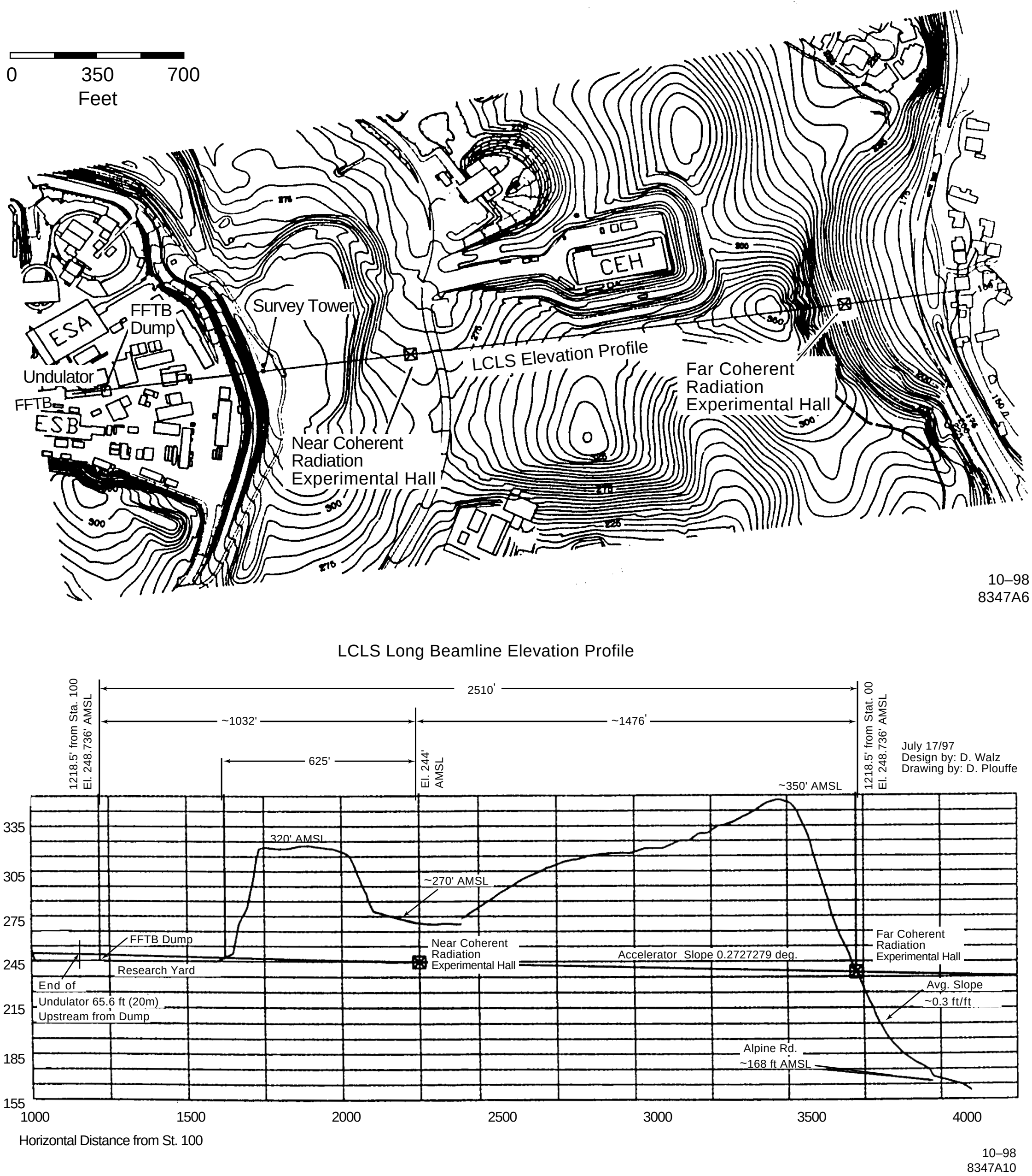


Figure 1: LCLS-II Layout Schematic

Figure 2: LCLS-II Layout Overlay on SLAC Site



3. LCLS-II Gun & Laser Discussion

Gun Laser

A laser oscillator is used to create the pulse train structure. In the present LCLS-I design, a commercial oscillator is modified to provide a single pulse and accommodate the timing stability of σ_{rms} = 0.5 ps that the FEL requires. Commercial laser oscillators incorporate cavity lengths that correspond to approximately 8–10 ns spacing between laser pulses. This corresponds very well to the required bunch separation in the nominal 40 bunch LCLS-II design and the same commercial oscillator can be used.

In the case of a 3.25 ns bunch spacing a short-cavity-length oscillator will have to be designed and constructed. The main reason for the 8–10 ns spacing between laser pulses in commercial Ti-Sapphire oscillators is because they compensate the dispersion that originates in the laser crystal (due to the high intensities involved in the Kerr-Lens mode-locking scheme) by using prisms. These prisms typically occupy a large volume of the optical cavity making the roundtrip length, and hence the spacing between the laser pulses, long. To design for shorter pulse spacing, it may be possible to use “chirped mirrors”. Currently there is a manufacturer of chirped mirrors. The mirror curvature needed in a short cavity length is very high and the combination of chirping of the mirror and high curvature will have to be investigated. This proposed short length laser oscillator would be essentially identical to the NLC source laser oscillator since the pulse spacing is similar.

In the existing LCLS-I design the laser amplifier is not regenerative. This alleviates any problems for multi-pulse operation. Compensation for gain depletion can be achieved by ramping up the power of the pump laser in the time scale of 350 ns (the fluorescence time for Ti-Sapphire is 3 μs).

At the proposed LCLS-II laser intensities optical damage is possible after frequency tripling to UV. Data in literature is inadequate to understand the interplay of the two regimes of short picosecond pulses (micro-pulse) that ablate the surface of dielectric materials and of long pulse trains (macro-pulses) that create damage by heating the optical surfaces. The time scales for optical damage due to multi-photon processes on the optical coatings are long compared to a week of photoinjector operation and replacing critical optical components on a regular basis can easily be folded into the photoinjector operation.

Photocathode

The most important issues for the gun photocathode design for the LCLS-II are response time, charge depletion and optical damage.

In the current LCLS-I design copper is used as the cathode material for the RF gun (there is an R&D plan to study Mg and other materials). Data for the time response of copper are found in the literature, but in most of these data, the charge created is less than the 1 nC required for the LCLS. For example, at the European UV Laser facility in Crete (IESL-FORTH), Cu had a measured response of better than 0.5 ps. This measurement was limited by the pulse width of the driving laser. As such the copper photocathode response time is not expected to be an issue for the LCLS-II.

The “charge depletion limit” is another issue for photocathodes. It was first observed at SLAC in GaAs cathodes used for DC guns. Measurements showed that the pulse, extracted some tens of ns after the first pulse, has less charge. The physics of metal cathodes is different and there is no reason to expect such an effect but nevertheless copper and other metal cathodes should also be tested in such high charge regimes. Some attempts to test this have been performed at BNL and the University of Rochester but for lower charge than required for the LCLS.

Damage of Cu cathodes in rf guns has been reported from some labs. However the data is not adequate to determine whether this damage was due to long term exposure to UV laser pulses, which could affect the pulse train operation, or to inadequate cleaning of the cathode or the very high electromagnetic fields used in RF guns.

RF Gun

The electron beam changes the RF match of the gun by inducing a variable load as the pulse train propagates through the gun structure. This “beam-loading” can be solved by varying β_{rf} as a function of the changing operational parameters. For example adjusting a load on a linear motion feedthrough on one of the arms of a waveguide Tee before it feeds the gun may do this. Multi-bunch operation will also require that the klystron has to be protected from excess RF power and the gun will have to be water-cooled.

Many other issues of multibunch operation have already been extensively addressed by the TESLA collaboration design for an L-Band RF gun in [2].

4. LCLS-II Linac Issues

RF compensation in the linac

RF beam-loading compensation in the linac has been successfully demonstrated (fixed target experiment E154) for a beam with 1.0 x 10^{11} electrons (16 nC) in a 350 ns batch. Experiment E158 that is proposed to run in the year 2000 requires the same batch but a total accelerated charge of 7 x 10^{11} (112 nC). The major challenge for such an RF compensation scheme is the requirement that $\Delta E/E < 0.1\%$. In addition, the measurement resolution for $\Delta E/E$ must be good enough for the compensation and feedback algorithms.

As is seen, the nominal beam charge parameters (40 nC in 40 bunches in a 350 ns batch) for LCLS-II operation introduced in this workshop are consistent with what has already been achieved in RF beam loading compensation in the linac. Even the smaller bunch separation option does not appear to be a big problem. The energy jitter for E154 was of the order of 2 x 10^{-4} and is similar to the LCLS-II requirements.

Wakefields

At a macro-pulse width of 350 ns and the high beam currents required for LCLS-II operation, higher order wakefields will have to be taken into account. The exact wakefield effect has yet to be calculated for the LCLS-II parameters. However, the tools for such a beam dynamics simulation (e.g. LIAR) exist already and have been successfully implemented for LCLS-I.

Another possible problem in LCLS-II operation may be the fast ion instabilities. Again the tools exist to estimate this effect have been used for the LCLS-I design, but as yet calculations for the LCLS-II design have not been done.

Bunch compressor issues

The tolerances on the single bunch (LCLS-I) intensity and timing jitter are stringent and are described in [3]. In order to keep the intensity fluctuation of the X-rays produced by SASE to less than the nominal 20-30% during multi-bunch (LCLS-II) operation these bunch parameters will have to be equally well controlled. It is believed that controlling the single bunch parameters is the major part of this problem and that the additional effort required for multi-bunch operation is not great.

5. Beam Switching

The macro-pulse accelerated in the linac is approximately 350 ns long, the length of the SLEDed RF pulse. Given the s-band bucket separation of 0.3501 ns, this corresponds to 1000 s-band buckets. LCLS-II will use RF separators to separate the pulse train accelerated in the linac into four separate beamlines. Using 15 MV of L-band RF separators running at one half the linac s-band frequency, the pulse can be made to have a +/- 1 mrad angular kick at 15 GeV. Using two such systems, one horizontal and one vertical, the linac pulse train is divided into four separate pulse trains at (+/- 1 mrad horizontally times +/- 1 mrad vertically). These four resultant beams have the full macro-pulse length of 350 ns. The bunch separation in the linac pulse train has to be an integral number of L-band wavelengths plus or minus one s-band wavelength, i.e. an odd number of s-band wavelengths, to effect the most angular separation. In the LCLS-II a separation of 25 s-band buckets (12 L-band wavelengths plus 1 s-band) is chosen. This leads to 40 bunches in the linac macro-pulse with a bunch separation of 8.754 ns which is relatively easy for the photoinjector and linac. It may be possible to accelerate even more bunches in a macro-pulse. A bunch separation of 9 s-band buckets (3.251 ns) will allow a total of 112 bunches, giving four beams of 28 bunches each. This option requires improved beam loading compensation in the linac and significant improvement in gun laser performance and will be investigated.

It may be possible to place the RF separators upstream of the muon-shielding wall at the end of the linac enclosure. In that case the drift space of 15 meters in shielding wall will cause a +/- 15 mm separation of the beams horizontally and +/- 15 mm vertically at the entrance to the Undulator Hall. This is more than sufficient to make the four particle beamlines in the Undulator Hall. The beamlines will be in a transverse two-by-two matrix. Each beam will pass through its own undulator. The individual undulator parameters will be optimized as required by the experimental scientific program.

After the Undulator Hall both the particle and radiation beams are transported into the Spontaneous Radiation Experimental Area. The FEL radiation beams go straight through. The “spent” electron beams are further used to make spontaneous radiation beams by passing through series of bends and short undulators and then are dumped (these spent beams are of good enough quality to be used as test beams for any other purposes, e.g. HEP needs, as well). The four FEL beams pass through the Spontaneous Radiation Experimental Area and through the X-Ray Transport Line I to the Near Coherent Radiation Experimental Hall. The X-Ray Transport lines are simply evacuated beampipes approximately 1 meter in diameter tunneled through the ground. The Near Coherent Radiation Experimental Hall is approximately 200 meters from the end of the Undulator Hall at a depth of 10 meters. Here one or more of the FEL beams will be split into many (e.g. 4) radiation beamlines which can be used for experiments. The rest of the FEL beams are sent through the X-Ray Transport Line II to the Far Coherent Radiation Experimental Hall. This hall, at 700 meters from the Undulator Hall, is as far from the Undulator Hall as is possible while still staying on the SLAC site. Here the remaining FEL beams are split into many radiation beamlines and fed into experimental beamlines.

There are three techniques that could be used for splitting the FEL beams into multiple optical beamlines, i.e. specular, diffractive and refractive. Before addressing these techniques, three ancillary approaches to mitigating peak power damage should be noted [4]. The use of any of these will impact the specific details of the implementation of any switching technique. First, the LCLS output could be passed through an absorption cell prior to switching. While easing switching requirements when on, damage issues would resurface when operating without it. Second, long beam lines for the FEL radiation are advantageous. By allowing the optical spot size to grow because of the FEL beam divergence, safer optical switching can be performed. The present SLAC site boundary would limit the length of the primary + switched beam lines, so the long primary beamline needed for safer optical switching may limit the lengths of the switched beamlines. Third, special optical elements for expanding the beam prior to switching could be implemented, but peak power damage issues, again, would necessitate exploratory R&D in the design, fabrication, and operation of such devices.

Specular

There are two possible modes of deflecting or switching LCLS radiation pulses into different beam lines with mirrors: static and dynamic. In the static mode different parts of the beam could be intercepted by different mirrors placed at the same or different angles, as is done, for example, on Beam Line 4 on SPEAR. The unintercepted part of the beam would feed the beamline with the full energy range of the LCLS's coherent line and spontaneous radiation spectra, while the beamlines, fed by the deflected portions of the beam, would have softer upper energy limits determined by their mirror materials and angles of incidence. Damage concerns would probably necessitate the use of very small interception (and deflection) angles and consequently long mirrors (on the order of 1 m in length). Reflectivity curves for various materials spanning the energy range of the LCLS are shown in Fig. 3, with the corresponding energy loading curves of the mirror materials graphed in Fig. 4. At the presently anticipated 25 m distance between the first mirror tank and the undulator exit [5] the small size of the coherent beam waist (~125 μm) would make this approach to deflecting the FEL beam difficult to implement with more than one mirror. The task would become considerably easier with a substantially increased beam waist size, i.e., at locations several hundred meters farther downstream, or with the implementation of an effective beam expander.

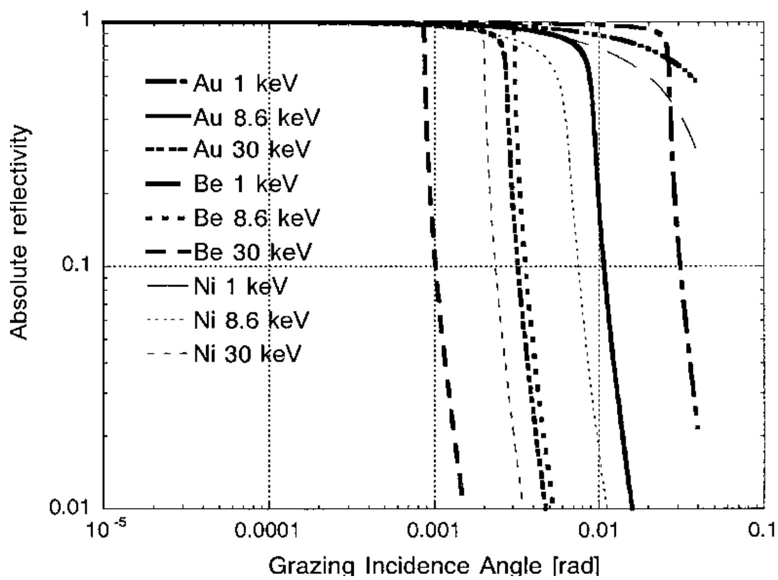


Figure 3. Reflectivity (TE) of candidate LCLS mirror materials vs. grazing incidence angle and LCLS energy.

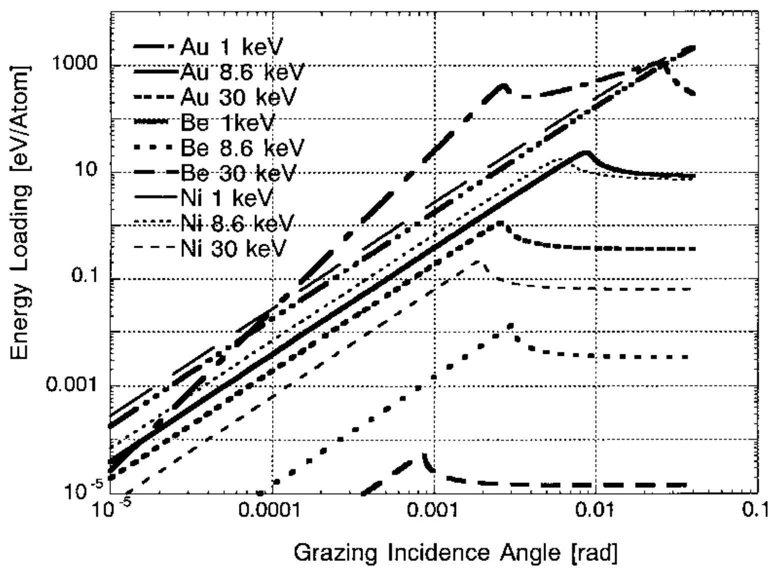


Figure 4. Peak power energy loading of candidate LCLS mirror materials vs. (TE) grazing incidence angle

A dynamic switching approach could be based on the rapid vertical displacement and cycling of a vertically stacked bank of mirrors [6,7]. The different mirrors would have slightly different interception angles corresponding to the different beam line directions, and would be timed to intercept the beam at a 120 Hz repetition rate. The peak power damage issues would be the same as in the static mode, but the switching method would be more flexible. For example, more beam lines could be created and the duty cycle of any beamline could be varied by altering the timing and range of the mirror bank motion. On the other hand, since this technique hasn't been implemented, to our knowledge, at any synchrotron radiation facility to date, it should be considered as an R&D option, with its viability dependent on the successful development and proofing of adequate motion control and detection/feedback systems and techniques.

Diffractive

Diffraction could also be used to split and re-direct the LCLS beam. In view of the specific energy ranges of the LCLS coherent line (160 eV - 25 keV through the 3rd harmonic) and spontaneous (up to >1 MeV) spectra, this approach could employ periodic microstructures (e.g., transmission gratings) over the full spectral range and crystals at energies higher than, say, 5-6 keV. In this approach, the beam is transmitted through a periodic structure which diffracts into the 1st and -1st (and possibly a few next-higher) orders with substantial efficiency. These orders are effectively monochromatized (to within the presence of higher order harmonics), while the transmitted 0th order beam carries approximately the full source spectrum of the LCLS. A scheme of this type, based on a diamond crystal, has been successfully implemented at the ESRF [8]. On the LCLS, this technique would be more problematical due to firstly, the above-mentioned likelihood of peak power damage, and secondly the considerably broader spectral range of the LCLS. In the first instance, a dynamic approach could be used to mitigate damage effects, viz., the crystal or microstructure could be successively moved between LCLS pulses to undamaged interception points [9]. Alternatively, microstructures based on shaped or density-modulated gas or liquid jets [10] could be employed. In the second instance, movable and rotatable crystal configurations could be developed to help maintain fixed directions of the deflected beams vs. photon energy. In view of these various possibilities and attendant complications, the ultimate viability of the diffractive approach is also likely to depend on a successfully-prosecuted exploratory phase of R&D.

Refractive

This method of beam deflection can be viewed as a limiting case of diffraction, in which the change of beam direction is induced by a monotonic phase gradient induced in the beam transversely to the direction of motion. Due to the nominal absence of a finer periodic structure, an element of this type (essentially a prism) would be (also nominally) less difficult to develop and fabricate than a periodic microstructure. A simple example would be a gas jet with a varying density gradient. A single element of this type would have the drawback of deflecting the entire beam in one direction, but this could be used to advantage for feeding multiple beam lines if the prism parameters could be cycled repetitively (over an adequate dynamic range) at a 120 Hz rate.

Other difficulties inherent problem in this approach would be the limitations imposed by absorption in the prism material, or very small deflection angles should operation need to be limited to overly low density, low-Z gases.

6. Spontaneous Radiation Beamlines Layout and Physics

The electron pulses exiting the FEL undulators, though modified by their FEL passage, still maintain useful qualities for producing synchrotron radiation. In particular, they maintain very high peak current and sub-picosecond bunch length. An LCLS-II user facility will exploit these characteristics by providing beamlines that produce spontaneous synchrotron radiation using the "spent" FEL electron beams. The magnetic devices producing this spontaneous radiation are physically very similar to the undulator and wiggler insertion devices commonly found in storage ring-based synchrotron sources (i.e., typical length of 2-5 m and magnetic field of 1-2 T), and will have relatively low unit cost. The optics required for using this spontaneous radiation are not required to handle the very high peak radiation loads of an FEL pulse, or the very high average loads of a 3rd-generation synchrotron source, making them also relatively inexpensive.

The Spontaneous Radiation Experimental Hall, which will house the spontaneous radiation beamlines, lies just downstream of the Undulator Hall and will be approximately 800 sq. meters in area. The FEL radiation will pass straight through the center of the hall. The "spent" electron beams coming out of the undulators are bent in the horizontal plane and follow arced trajectories in the hall and are then dumped. The short wigglers/undulators are placed along these arcs and experimental hutches will be placed to take advantage of the radiation so generated. The hall is sized large enough to comfortably to accommodate sixteen hutches, the various beamlines, the beam dumps and associated equipment.

Reflecting the high peak current in the electron beam, the spontaneous radiation from a 2-5 m insertion device has a high peak flux and peak brightness. Though these values are many orders of magnitude less than those of the FEL beam, they are none-the-less 10-100 times larger than the peak flux and brightness values of a 3rd-generation synchrotron source. The pulses are also shorter than those obtained from 3rd-generation sources, by a factor of 100-1000. This is very useful for fast time-resolved x-ray experiments which need to go beyond the capabilities of 3rd-generation sources, but do not need the extreme brightness of an FEL beam.

Because the duty cycle of the LCLS-II is much lower than that of a 3rd-generation source, the average flux and brightness values of the spontaneous radiation beams are as much as 6 orders of magnitude lower in the angstrom-wavelength region. However, due to the 15-GeV energy of the LCLS-II electron beam, at very high photon energies (above 500 keV) the LCLS-II spontaneous radiation beams is unsurpassed even in average flux. The LCLS-II will produce broadband, highly collimated spontaneous radiation up to about 2 MeV, which will have a great impact on the fields of gamma-ray spectroscopy and gamma-ray diffractometry.

7. Coherent Radiation Beamlines Layout and Physics

The FEL radiation beams generated in the undulators exit the Undulator Hall and pass through the Spontaneous Radiation Experimental Hall. They then go through the X-Ray Transport Line I to the Near Coherent Radiation Experimental Hall. This hall is approximately 300 meters from the Undulator Hall and is approximately 200 sq. meters in area and approximately 8 meters underground. It will have room to split one of the radiation beams and send the split beams to four experimental hutches. In addition it will house the devices that will control the peak optical FEL power such as gas attenuation cells or devices that will increase the FEL beam divergences so that they are easier to handle further downstream. The remaining FEL beams then are transported through the X-Ray Transport Line II to the Far Coherent Radiation Experimental Hall. This Hall is approximately 700 meters from the end of the Undulator Hall and is approximately 800 sq. meters in area. Each of the remaining three FEL beams will be split into four separate optical lines. The hall will be big enough to accommodate the FEL beam splitters, the experimental hutches and associated equipment

The key attributes that differentiate an FEL radiation source from a conventional synchrotron source are its very high peak brightness, ultra-short time structure, and very high coherence. It is expected that FEL experiments will make use of these qualities, and will need to tailor them to specific requirements. Thus an effective user facility should offer some ability to control them. Other radiation attributes for which experiments may have specific requirements include polarization (circular polarization can be effectively prepared by a helical FEL undulator), energy tunability (most easily achieved through changes in the electron energy), and energy chirp.

In addition to requirements for the radiation itself, user experiments will place demands on the beamline optics, time-sharing system, sample environment control, and data collection and analysis systems. Many of these requirements are similar to those experienced at a synchrotron user facility such as SSRL. Others specific to the LCLS radiation have been discussed in depth in [4].

As has been concluded by several workshops on the scientific applications of short-wavelength FEL's — most notably the Workshop on Scientific Opportunities for Fourth Generation Light Sources, held at the Argonne National Laboratory on Oct 17-29, 1997 — exciting FEL science will be found throughout the short-wavelength spectrum, from the UV into the hard x-ray region. While great progress has recently been made at coaxing conventional lasers to generate radiation in the UV, and while small FEL facilities under construction (such as the DESY TTF-FEL project) will be able to reach wavelengths down to around 100 Å, it is unlikely that any laser facility besides the LCLS will be able in the near future to access wavelengths at or below the so-called water window (20-40 Å, covering the region between the 1s absorption levels of carbon and oxygen). Therefore, while the original LCLS design calls for a spectral range of 1.5-15 Å, it will be highly desirable to extend this range in both directions, from at least 40 Å down to the smallest wavelength achievable. The LCLS-II lowest energy of 2 GeV enables wavelengths up to 77 Å. The third harmonic has very respectable characteristics and extends down to 0.5 Å. Since the optical techniques used vary greatly across this spectrum, it would be best to assign different spectral regions to the various undulator sources described in the previous section.

The scientific case for the LCLS is briefly summarized in section 3 of the LCLS Design Study. A workshop is planned for January 12-14, 1999, where the scientific opportunities with the LCLS will be discussed in more detail.

8. Summary

This paper has demonstrated that it is quite feasible to extend the LCLS as envisioned in the LCLS Design Study Report to a full user facility with tens of experimental beamlines. An initial path to a nominal facility with 16 FEL radiation beamlines and 16 spontaneous radiation beamlines has been mapped. The FEL radiation beamlines will have extremely high peak brightness with a wavelength range of 0.5–77 Å and spontaneous radiation beamlines will provide useful photon fluxes up to >1 MeV. No insurmountable difficulties have been identified. More work is required to optimize the design and to determine the most useful mix of wavelengths needed for the experiments.

Appendix 1.

Agenda

8:30-9:00	Coffee and doughnuts
9:00-9:15	Welcome and introduction (M. Cornacchia)
9:15-9:45	LCLS-I parameters (H.-D. Nuhn)
9:45-10:15	LCLS geographical layout and possibility for expansion (D. Walz)
10:15-10:30	Initial ideas for more bunches and beamlines (V. Bharadwaj)
10:30-12:30	Groups meet
12:30-1:30 pm	Lunch in cafeteria
1:30-3:00	Groups meet and reports are prepared
3:00-5:00	Reports of working group leaders

Working Groups & Leaders

Photoinjector/linac	T. Kotseroglou/V. Bharadwaj
Switching	K. vanBibber/V. Bharadwaj
Advanced concepts	C. Pellegrini
Beamlines	I. Lindau

Participants

J. Arthur, K. Bane, V. Bharadwaj, S. Brennan, R. Carr, M. Cornacchia, T. Cowan, F.-J. Decker, A. Fisher, J. Frisch, G. Travish, M. Hogan, W. Kirby, T. Kotseroglou, G. LeSage, I. Lindau, R. Miller, H-D Nuhn, D. Palmer, C. Pellegrini, P. Pianetta, T. Rabedeau, D. Reis, M. Ronan, J. Schmerge, G. Stupakov, R. Tatchyn, K. van Bibber, D. Walz, H. Winick

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