Summary of Recommendations from the Lehman Review on April 23-25, 2002

Accelerator Physics

Continue to give high priority to experimental benchmarking of the computer codes used to model the injector

Work has continued on benchmarking injector design codes. Comparisons with experiments have been published[1]. The results of thermal emittance measurements at the BNL DUVFEL and at the SSRL Gun Test Facility (GTF) were simulated in detail, confirming a value of 0.6 mm-mrad per mm spot radius. This value, larger than theoretical predictions, has been included in all simulations relevant to the LCLS. The slice emittance experiment at the DUVFEL was simulated including cathode emission non-uniformity and longitudinal pulse profile. Good agreement was obtained for slice emittance values and Twiss parameters along the bunch for various solenoid values after appropriate meshing was used.

Quadrupole scan emittance measurements were performed at the SSRL Gun Test Facility, and compared to PARMELA simulations [2]. The comparison showed that it is important to fit the "tails" in measured beam profiles down to a level of 2.5% of peak, after noise extraction. This is applied to the GTF emittance analysis.

The longitudinal emittance measurements performed at the GTF have been compared with simulations[3]. Good agreement has been obtained between simulations and experiment after longitudinal wake fields in the linac section were included.

The predictions of several gun design codes have been compared[4]. Both PIC codes and PARMELA, which use a very different representation of the physics at the early stage of acceleration of a beam leaving the cathode, agree well. A 3-D model of the LCLS gun with input ports correctly included shows negligible effects on the dynamics from quadrupole field components.

PARMELA, ASTRA, HOMDYN, TREDI and BEAMPATH results were compared for the LCLS Photo-Injector beamline up to the first linac section[5]. All those codes give similar beam characteristics (transverse and longitudinal emittances, and Twiss parameters) once meshing and time steps have been optimized for each code.

Transverse wake fields have been included in PARMELA. With this new feature, tolerancing on component positioning has been done[6].

Pursue experimental investigation of bunch compression and its comparison to theory.

Considerable progress has been made in understanding coherent synchrotron radiation (CSR) effects during the bunch compression process. The January 2002 CSR Workshop held at DESY-Zeuthen prompted a remarkable theoretical effort at understanding CSR. By the time of the ICFA Beam Dynamics Workshop held in Sardinia, 1-6 July 2002, considerable progress had been made. A theoretical treatment of the CSR micro-bunching instability throughout the bunch compression process in the LCLS has been carried out, which includes the interaction of all stages of compression[7].

A bunch compressor chicane has been installed at the 9 GeV point in the SLAC linac, and experimental investigations of CSR with a 3.4-nC, 150-fs electron bunch are underway. The predicted emittance growth is 22% (initial emittance of $\gamma\varepsilon_{x0} \approx 27$ μm increases to 33 μm) and measurements with this initial emittance show 33.6±0.3 μm. Although this is a small signal, the measurements are consistent with the calculations and set an upper limit to the effect[8]. Unfortunately, since the incoherent energy spread of the SPPS bunch is quite large, the CSR micro-bunching instability is completely suppressed and should not be observable.

Other studies making use of the new bunch compressor are yielding results of importance to the LCLS. Considerable experience has been gained in the tuning and measurement of short bunches in the linac as well as acquiring knowledge of the stability of the short bunches with respect to the RF accelerating phase and amplitude[9]. Bunches down to 50 microns (150 femtoseconds) rms length have been measured at the end of the linac using an RF transverse deflection cavity, identical to that planned for the LCLS. Diagnostics and instrumentation have been tested for the first time with compressed bunches, providing information relevant to design of automated beam feedback systems to hold machine parameters constant during beam scans. Linac wake fields have been measured and compared to analytical models for the wakes in the SLAC S-band accelerating structure[10]. The effects of these wake fields have been included in the bunch compressor dynamics.

Continue to develop tolerance budgets and optimize the performance by use of start-to-end simulations

Work on start-to-end simulation is continuing as before[11,12,13] using the output of each stage of the modeling exercise as input to the next stage. A workshop on the subject of start-to-end simulation will be held at DESY Zeuthen, 18-22 August 2003. The workshop will address issues of numerical accuracy and approximations of the physics. Workshop participants will perform numerical simulations of “benchmark” beam- and FEL physics problems to assess accuracy and compatibility of codes.

Study SASE output versus electron bunch charge to investigate the possibility that LCLS performance goals can be achieved for charges lower than 1 nC.

The full operational range between 0.2 nC and 1 nC has been examined using start-to-end simulations in the wavelength range between 1.5 A and 15 Å. The electron beam

properties for the low charge regime have been based on GTF measurements. For the lower charges, the saturation length increases by 10-20% for the lowest charges, while the saturation power levels decrease by about a factor 10.

Injector and Linac

Establish a resource-loaded schedule for the PED by September 2002

The PED funding profile has been set for FY2003 and 2004, and planning efforts have emphasized long-lead procurements in 2005 and the effort required to prepare for this activity. The baseline for the entire LCLS Project will be presented for review in April 2004.

Establish a realistic spares list and include in Other Costs of other appropriate area by September 2002

As mentioned above, present efforts have concentrated on long-lead procurements in 2005 and the spares that are most efficiently procured at the same time.

Include support for the required injector scientist activity in the commissioning plan by September 2002.

Injector scientist support at the three-person level will be provided during LCLS commissioning. This level assumes two scientists performing beam measurements and data analysis, and a scientist running simulation codes which model the measurements. In addition, there should be one laser scientist supporting the drive laser operations.

Move forward with laser prototyping as early as budget permits. Include planning by next review.

Early laser prototyping will be difficult given the FY03 and FY04 funding levels. However effort will emphasize transverse profile flattening using an aspheric optic and single shot pulse characterization using FROG techniques in the IR and UV. This prototyping will be done at SLAC using the Gun Test Facility (GTF) drive laser. In addition, there is the opportunity to collaborate with the Italian SPARC project on pulse shaping in a Ti-Sa laser. This drive laser is similar to the LCLS drive laser and will use an acousto-optic dispersive filter called the DAZZLER. This device is described in the proceedings of an LCLS Workshop addressing “Laser-Issues for Electron RF Photoinjectors”[14] held at SLAC in October 2002.

Move forward with prototyping the gun as early as budget permits. Include in planning by next review.

Progress in these areas will be presented at the 2003 Review.

Perform prototyping and design validation tests on the GTF test stand, integrating as many of the injector components as possible before final integration on the injector linac. Include in the TPC. FY02-FY03.

The GTF has been upgraded to provide higher accelerating gradient. A magnesium cathode has been installed. This, combined with upgraded laser power, will make it possible to thoroughly characterize the performance of the LCLS gun at GTF.

Slice emittance from an s-band gun with a copper cathode has been measured at GTF for low (15 pC) and moderate (290pC) charge beams[15]. The low charge data provide an estimate of the thermal emittance or the limiting slice emittance expected in LCLS. The result is in good agreement with a thermal emittance measurement made at BNL using a very different technique. Slice emittances were also determined at GTF for a moderate charge beam with a similar peak current (130A) as required for LCLS. The data showed a good slice emittance of 1.5 microns at a high instantaneous peak current of 130 amperes. The experiment also demonstrated the much higher 3 micron projected emittance was due not only to mismatch of the slices but also relative offsets of the slices in transverse phase space[16].

Testing of an electro-optic bunch length and timing diagnostic is planned at GTF. Similar to the device envisioned for the LCLS Injector, the prototype uses unconverted green light from the drive laser in an electro-optic crystal to make the measurement. The signal from the prototype when compared with the RF phase is a possible source of timing control for LCLS.

Funds permitting, the feed forward control of the gun will be studied at GTF. Feed forward allows the gun to reach the desired high electric field in less time, significantly reducing the power dissipation in the gun. This reduces the amount of thermal engineering and hence the cost of the gun.

Undulator

Designate a senior team leader for the LCLS undulator system from within APS whose primary responsibility is to carry forward to successful completion the system before September 2002.

Dr. Stephen V. Milton assumed directorship of the LCLS-ANL Project. His leadership of the ANL LEUTL FEL program makes him uniquely qualified to lead the LCLS Undulator Systems effort.

Develop a resource-staffing plan prior to expenditure of PED funds to meet the requirements during PED design phase by July 2002

Staffing requirements for the undulator effort are under review at this time. It is expected that some reduction in overall staffing requirements at ANL can be realized. More

detailed planning will address the peak manpower requirements necessary to meet Project goals.

Decide on the undulator procurement approach by September 2002. This must include who, national lab or industry, will be responsible for what portions of the design, fabrications, measurements, etc. The approach during the preliminary design phase is different depending on the approach.

The plan for acquisition of the undulator will be presented at the 2003 review.

Complete a thorough engineering and production analysis of the undulator mechanical design. Trade offs on the choice of strongback materials, thermal compensation and phasing control, physical tolerances, and relationship between stringent tolerances and post-assembly tuning must be completed. This is to be completed prior to submitting for bid any long lead procurement.

The characteristics of the prototype undulator have been investigated and documented[17,18,19,20]. A more comprehensive report of the 1st prototype undulator is to follow and will be part of the basis for procurement of the undulator long-lead items.

Focus the second undulator prototype on addressing mass production issues. The design and technical approaches are sufficiently advanced that production issues are the most urgent. If a second prototype is pursued, this recommendation must be completed prior to CD-3. If industrial production is selected, the second prototype should be produced in industry.

The plan and schedule for the second prototype undulator will be presented at the 2003 Review.

Build and field a complete prototype subsystem consisting of an undulator (the existing prototype is adequate), vacuum chamber, a short diagnostic/focus section, and a long diagnostic/focus section. This should include the electron beam diagnostics and x-ray beam diagnostics. This is to be completed prior to CD-3.

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A prototyping plan for the entire undulator system will be presented at the April 2004 Review. Emphasis will be placed on confirming that critical components and subsystems meet the performance requirements. Where possible, this will be done by tests with beam. Due consideration will be given to constructing a prototype subsystem. In planning this activity, emphasis will be placed on thermal stability, vibration and motion control.

Assess and ensure that the allocation of the total impedance budget throughout the undulator is complete before CD-2. Specifically, the cavity BPM, x-ray diagnostics, and Cerenkov detector disruptions will impact the allocated impedance of the system.

An impedance budget will be determined by SLAC and transferred to ANL by CD-2. ANL will ensure that the vacuum system for the undulator system meets or beats this allocation.

Installation and alignment

Continue to optimize the approach for minimizing installation interference with linac operations for other programs.

Incorporate plan for injector commissioning with installation of other systems by next review.

Laser commissioning activities can begin as soon as the laser is installed at sector 20. Injector commissioning can proceed in FY2007 without interference with installation in the FFTB. The second bunch compressor installation can take place in the third quarter of FY2007, in coordination with commissioning of the injector. This will permit FEL commissioning to start at the beginning of FY2008. A fully integrated Project schedule will be provided at the April 2004 Review to support the request for CD-2 approval.

Photon Beam Handling Systems

Increase R&D in the damage area as much in advance as possible before experiments take place. At the same time calculations of optical component performance must also be pursued.

Calculations of optical component performance are underway at this time. The calculations will be benchmarked against data taken at SPEAR in February 2003. Damage Studies will be pursued using the Sub-Picosecond Pulse Source (SPPS) after installation of focusing optics in the fall of 2003. LLNL is calculating the conditions (materials etc.) under which relevant damage experiments can be done at SPPS.

Increase communication with undulator x-ray diagnostic group.

A biweekly LCLS teleconference has been established for this purpose. Every effort will be made to increase communication with x-ray optics/diagnostics experts at both LLNL and ANL.

Increase R&D to measure temporal resolution, achieve pulse timing, and measure pulse chirp.

This is an active area of research as part of the SPPS experiment, and LCLS will participate in and benefit from the results of this research. A candidate technique for pulse length and synchronization measurements at LCLS was tested in SSRL runs in January and March 2003.

Ramp up additional staff with laser expertise on the project at SLAC for commissioning.

A postdoctoral appointment has been filled in support of the SPPS experiment. LCLS intends to hire a laser/optics engineer in FY2004. A successful LCLS science program will require SSRL/SLAC participation in planning and design of experiment facilities. Staffing for support of this program will reflect the important role that lasers are expected to play in LCLS experiments.

Include laser specialists and experienced synchrotron radiation users/beamline designer as an integral part of the advisory committee. Consider renaming the Machine Advisory Committee to Facility Advisory Committee.

Laser experts have been included in the LCLS Facility Advisory Committee and Science Advisory Committee

Evaluate the shielding requirements for the connected tubes and other elements.

LCLS Management and staff recognize the need to focus on the general issue of radiation shielding in the early stages of the facility design, and the design of all beamline components. Appropriate collimation and shielding will be designed to insure that radiation levels in LCLS are ALARA.

Assess contingencies based on individual component risk analysis.

X-ray systems PED activities will address risk associated with each component and will draw upon previous experience gained in the laser field as well as that gained in the synchrotron community worldwide.

This will be done as part of preparation for determination of the baseline in April 2004.

Incorporate lessons learned from 3rd generation light sources for developing optical component specifications and beamline component design.

LLNL-LCLS personnel are in close contact with SSRL and SPEAR-III personnel. Communication is maintained through weekly meetings as well as through research activities carried out by LLNL personnel on site at SLAC. The testing of LCLS prototype camera and optics at SSRL is done in close coordination with SSRL accelerator, beamline, x-ray, and safety personnel. The design and specification of the mechanical systems (fast valve, shutters, control, etc.) begins with designs of similar systems at SLAC in consultation of the responsible SLAC engineer. LLNL maintains an office at SSRL. ANL is an invaluable source of beamline component expertise although the distance between SLAC and ANL precludes numerous and frequent visits between the sites. Nevertheless, every effort will be made to exploit the experience of beamline designers at SSRL and ANL. This will be facilitated through the regular communication provided by the bi weekly LCLS management videoconferences.

Control Systems

Consolidate the controls effort under one organizational entity within the LCLS Division. Consider consolidation of the controls WBS elements as well.

Overall responsibility for management of LCLS controls will be assigned to a single task manager reporting to the SLAC Project Director. Although the WBS has not been reorganized to combine controls work at all participating laboratories into a single WBS, it will be possible to implement the necessary management controls within the LCLS organization.

Centralize at SLAC the design and development of "global" systems, including timing, Machine Protection System and network. Establish standards for naming, technical database and appropriate hardware and software to be applied across the Project.

The Project accepts this advice.

Initiate discussions with LLNL to understand the interface requirements between the x-ray control systems and the accelerator control systems. (Communication with the Undulator controls team at Argonne has already been initiated).

The Project accepts this advice. LCLS-LLNL personnel are active in the SPPS experiment, which will serve as a good example of an x-ray experiment using SSRL equipment and software, integrated with the SLC controls system.

Conventional Facilities

Develop, document and control the top level System Design Requirements for the CF to ensure that the Conceptual Design Report and estimate are adequate by July 1, 2002.

The Conventional Facilities design is undergoing review at this time. The Near Hall size, placement and programming are being reevaluated to optimize its functionality with respect to use of the Far Hall. In particular, a smaller and simpler Near Hall is receiving consideration. The Near Hall programming will be finalized by September 2004, to support preparations for CD-2 in April 2004.

Further define System Design Requirements by the completion of Title I.

All LCLS conventional facilities requirements, design and cost estimate will be prepared for CD-2 approval in April 2004.

Augment the CF team with more experienced individuals; assign the CF team directly to the LCLS Project Team prior to the start of the Title I development. Engage additional consultants as required to augment the CF Project Manager to develop cost estimates, schedules, and other plans during Title I.

LCLS plans to begin Title I design by engaging one or more A/E firms to prepare site evaluations based on LCLS conventional facilities requirements. The LCLS CF team will consult with an outside A/E firm to provide advice concerning current plans and estimate prior to Title I development. It is expected that this activity can be completed before the end of FY2003.

Develop a Procurement Plan for the CF work and identify approaches and schedules

Procurement plans for LCLS conventional facilities will be prepared to support CD-2 Approval in April 2004.

Perform the geotechnical/biotechnical survey now, with the final report due no later than 9/1/02.

A requisition for the geotechnical survey is presently in process. The geotechnical exploration will begin before the end of May 2003.

Revise the project schedule to perform Title-I design of the CF in concert with the rest of the project, but not later than CD-2.

The conventional facilities schedule will be integrated with the overall LCLS schedule to support CD-2 in April 2004.

Revise the allocation of contingency to approximately 30%. This is due to the lack of detail in the CDR. As more detail is developed; the contingency should be reduced commensurately.

The contingency analysis for the Conventional Facilities cost estimate will be completed to support CD-2 in April 2004.

Cost and Schedule

Cost estimates need to address the committee's concerns - Reevaluate project contingency - especially in conventional facilities

See response above

Develop a TPC that includes updated TEC and details OPC includes R&D, Capital Equipment, Commissioning, etc.

Following the April 2002 review, LCLS Project Management and BES established a funding profile, including Other Project Costs, to serve as guidance for CD-2 preparations. This guidance included
-additional R&D funding in FY2004-FY2005
-a TEC of $223.5M

-an increase in PED from $33.5M to $36M
-planning for $29.9M in long-lead procurement funds in FY2005
-a start of civil and other construction in FY2006, with Project completion in FY2008
-planning for $8M of special process spares
-planning for a total of $31.2M in pre-operations funds, spread over FY2006-2008.

Develop a schedule with critical path including resources to provide support and verify assumptions:

- *Staffing levels*
- *Funding Profiles*
- *Cost estimates*

Schedule and staffing to support long-lead procurements in FY2005 will be presented at the 2003 Review. A complete resource-loaded schedule will be prepared to support CD-2 in April 2004.

Project Management

Documentation

- *Conventional Facilities part of CDR needs more detail*
- *Acquisition Execution Plan must be revised per recommendations*
- *Project Execution Plan must be revised and completed to support CD-1 by July 2002*

The Conventional Facilities design will be developed in greater detail with PED funds provided in FY2003-2004.

The Acquisition Execution Plan was revised in response to the recommendations of the April 2002 Review, and was approved by DOE 16 October 2002.

The Preliminary Project Execution Plan was approved by DOE on 20 September 2002.

Risk Assessment

- *Do a more quantitative risk assessment*

Risk assessment activities to date have focused on technical risks associated with saturation at 8 keV, based on start-to-end simulations of the LCLS with conservative performance goals for the electron beam. The results of this assessment have been given due consideration in long-lead procurement plans for the undulator, which will be presented at the April 2003 Review.

- *Create a plan that describes actions that could be taken to mitigate the high level risks that have been identified and then re-evaluate the contingency and schedule to take account of their potential impact and likelihood.*

A global risk assessment will be prepared to support CD-2 in April 2004.

Commissioning and Operations

- *LCLS should begin the coordination with the Technical and Research Divisions for compatible operations of the linac for HEP and of the LCLS during commissioning and operation of the LCLS.*

SLAC commitment to operate the linac for LCLS is a matter of SLAC policy. SLAC management is already scheduling shared operation of the linac for PEP-II, Endstation A experiments, SPPS and other FFTB activities. Time allocations are reviewed and approved by the SLAC director and Associate Directors.

Management of the Science Program

- *LCLS, SSRL and SLAC management need to define the advisory process for scientific input both on the experimental proposals and on LCLS design by January 2003. As part of this definition, they will need to determine the reporting structure for the SAC and/or other scientific advisory committees.*

The LCLS Scientific Advisory Committee will review, revise and approve the draft guidelines for instrument proposals before the end of FY2003.

- *SSRL will need to plan for the expanded range of activities involved in constructing and operating experiments for LCLS.*

The LCLS and SSRL management accept this recommendation. Since construction, installation and operation of LCLS scientific instruments will be the responsibility of SSRL and SLAC, it is anticipated that an SSRL liaison will be assigned to Instrument Development Teams starting at the pre-proposal R&D stage of development.

Overall Management

- *LCLS should adopt a performance capability to be reached at the completion of construction that will assure that major systems operate successfully and to guarantee that LCLS will ultimately achieve its required performance for science. This should be accomplished before the CD-1 Decision.*

The Preliminary Project Execution Plan has stated that “The top-level commissioning goal is to generate x-rays in the LCLS undulator and detect them in the Far Hall.”

- *Make improvements and corrections needed in CD-1 documents so that a CD-1 decision can be made in the July 2002 time frame.*

Requirements for CD-1 were met in support of CD-1 approval, which took place on the 16th of October 2002.

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[4] "Simulations Issues for PhotoInjectors" ICAPS02
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[14] http://www-conf.slac.stanford.edu/li-erp/
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