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LCLS TECHNICAL ADVISORY COMMITTEE (TAC) REPORT 1

July 14-15, 1999

TAC Committee Members Present:

Bill Colson (Chair, NPS)
Al Thompson (LBL)
Pat O'Shea (UMD)
Ross Schlueter (LBL)
Ron Ruth (SLAC)

The purpose of the Technical Advisory Committee (TAC) is to provide expert advice with regard to the R&D program of the Linac Coherent Light Source (LCLS). The report contains (A) general comments and sections on (B) the injector, (C) the accelerator, (D) the undulator, (E) FEL parameters and simulation, and (F) x-ray optics.

A. GENERAL COMMENTS

The TAC compliments the drive and enthusiasm of the LCLS R&D collaboration. The LCLS has covered a lot of ground in the past several years. It has moved from idea to voluntary research to a design report and now to funded work on a CDR. This is a big transition for the team which is composed of outstanding people and institutions. At this juncture it is important to clarify the project goals and implementation time scale to be compatible with the R&D nature of the project. In the future, we suggest that each talk focus on technical issues and problem areas rather than provide a review. Tutorials of new topics can be appropriate, but the TAC membership feels it is "on-board" technically and should concentrate on helping to solve problems.

Remember that the TAC is here to advise and help the project, and to do that effectively, we need to hear the things that worry you the most. Because the funding is limited, it is very important to establish priorities early. Some parts of the work may have to be underfunded or delayed initially in order to get early starts on high priority items.

We suggest that the next meeting take place in January 2000 and that it be two full days starting with one full day of presentations. The second day would begin with a morning of tours, or smaller working group sessions, with an afternoon for committee discussion and reporting. Thursday/Friday or Friday/Saturday dates would be better for collaborators and TAC members traveling from long distances.

A workshop with members of the table-top laser community may be technically fruitful. Collaboration between these communities is a key point of the Leone Panel on Novel Coherent Light Sources for DOE/BESAC in February 1999.

Also, we believe that several technical issues overlap with the scientific uses and we recommend collaboration between the TAC and the LCLS Scientific Advisory Committee (SAC).

The TAC notes that LCLS is described primarily as a research facility, but with a strong, though limited user base and with a capability for expansion. In light of this slant, LCLS may wish to start frank discussions and planning with partners regarding such a second phase and implications, if any, on the design of the current phase. One issue on which partners may differ is the choice of undulator technology. Perhaps the SLAC contingent will prefer the more conservative hybrid technology, emphasizing LCLS 's user rather than research nature, and the self-containment of the LCLS project. Conversely, the Argonne contingent may want to be more adventuresome with a riskier superconducting technology, that brings some performance advantages for LCLS, and which may be necessary for a second phase or next generation machine. The political, as well as the technical aspects of this issue need to be addressed.

At the next meeting, the TAC would like to hear detailed presentations on the relevance of VISA and LEUTL to the LCLS program. These presentations need to answer the question, "What will we learn from these experiments that we do not already know?" The unknowns are more likely to be in the injector/linac area rather than in the physics of the FEL interaction. Do VISA and LEUTL have sufficient electron beam diagnostics to give more information about the electron beam distribution than in any previous FEL experiment?

B. THE LCLS INJECTOR (Pat O'Shea, University Of Maryland)

The photoinjector is one of the smallest systems in LCLS, however, it is also the most important. Loss of beam quality in the photoinjector cannot be recovered elsewhere. Because the performance of the photoinjector will have great impact on the rest of the LCLS system, work on the photoinjector R&D program should be given the highest priority.

In many respects RF photocathode technology has achieved a certain level of maturity. One manifestation of this maturity is that there have been no significant breakthroughs in measured emittance in recent years. Gun designs have been developed that have sought to achieve the an rms value of 1 mm-mrad for 1 nC bunches (corresponding to the LCLS requirement), however the barrier of 2 mm-mrad has yet to be breached in an s-band gun of the type envisioned for LCLS use. Furthermore, the long-standing issues of cathode lifetime (and choice of material), drive-laser stability, beam diagnostics are still not completely resolved. Therefore, the requirements on the electron beam emittance for the LCLS will require some advances over the present state-of the-art, and will require the collaboration to solve essentially all of the existing problems of photoinjector technology.

The LCLS collaboration is well aware of these issues and has developed an R&D plan to deal with them. Five of the six collaborating labs have photoinjector experimental programs. The distributed nature of the R&D program could lead to a lack of focus. The Gun Test Facility (GTF) at SSRL should be a natural focus for the R&D efforts. At present, access to the GTF is limited because the vault is shared with the SSRL injector. Therefore, we recommend that the GTF be moved to the off-axis SLAC tunnel as soon as possible. The near-term experimental program at GTF should focus on the important issues of reducing the emittance and improving the system stability. The LCLS Collaboration has determined that drive-laser pulse shaping should allow the 1 mm-mrad emittance requirement to be reached on GTF. Detailed measurements should be made at low and high charge. Efforts should be made to measure the phase-space distribution directly at the gun exit. No Direct phase space measurements have been made on a low energy beam from a photoinjector. The physical configuration of the GTF allows the use of a streak camera to measure the phase-space distribution using Cherenkov radiation from a quartz screen.

The collaboration needs to develop a system design for the LCLS injector by late next year, yet there appears to be no clear path to such a design at the present time. All previous s-band photoinjector guns have been experimental devices designed to operate at low pulse repetition rate. The LCLS gun will be required to operate at 120 Hz. We recommend that the collaboration move quickly to develop a design that incorporates features associated with high repetition rate.

There is some evidence the design codes used to simulate the electron beam dynamics in photoinjector guns do not do a good job in the sub 2 mm-mrad emittance regime at 1 nC per bunch. We recommend that this topic be included in the agenda for discussion that the Theory and Simulation Codes Workshop in September.

<u>Summary of Iniector Recommendations</u>:

General issues:
* Improve the focus to the R&D program.
* Minimize the diffusion of effort among the *5* collaborators with experimental photoinjector programs.
* Give high priority to the development of system design for the LCLS.
* Include discussion of photoinjector simulation codes in the Theory and Simulation Codes Workshop in September 1999.

Gun Test Facility:
* Emphasize drive laser pulse shaping experiments.
* Perform direct measurement of electron beam phase space at exit of the gun using a streak camera.
* Perform detailed experiments from low to high charge.
* Move to the off-axis SLAC tunnel as soon as possible.

The TAC notes that a 2 it mm-mrad emittance is expected to be achieved by the end of 1999 and looks forward to hearing about this LCLS accomplishment at the next review.

In spite of the good simulations for the photo injector and because of the lack of experience with a working low emittance, it is important to explore the system parameter choices. For example, to be conservative initially one might assume a starting injector emittance of 2 mm-mrad plus a dilution of 1 mm-mrad. This will obviously lead to altered performance of the LCLS.

C. ACCELERATOR (Ron Ruth, SLAC)

There has been a lot of experience in preserving the low vertical emittance in the SLC. This experience has been folded into the LCLS design. There is an outstanding team of people working, and there are excellent plans for preserving the emittance while compressing and accelerating the beam. This results from a mature understanding of the phenomena. The emittance preservation process requires excellent instrumentation for both emittance measurement and bunch length measurement. This will allow tuning the system to achieve the required beam parameters. Start-to-end simulations are a great idea and must include all physics in the subsystems. It is important to continue the study of parameter tradeoffs as presented to the TAC, however higher emittance options should also be studied. It is critical that the design be very flexible. Coherent Synchrotron Radiation is a critical R&D issue. It should be an early experimental milestone. The balanced double chicane appears to be an excellent approach and it is possible the LEUTL could provide early BC1 validation.

It is now time to create design and experimental milestones for the effort. Examples might be the CSR milestone, emittance preservation milestone, accelerator alignment milestone, etc.

It is possible that Model Independent analysis could provide a beam-based method for accelerator alignment. The collaboration should explore the possibility of using the low vertical emittance of the electron beam from the SLC damping ring for early tests of dynamics and emittance preservation issues.

The TAC notes that the proposed alignment scheme based on Hamar Lasersystems components is untested. Early attention should be paid to this critical subsystem. A detailed schedule including a testing plan with milestones should be developed for this area.

D. UNDULATOR (Ross Schlueter, LBL)

The baseline strawman undulator design featuring the planar hybrid technology described in the December 1998 LCLS Design Study Report is a robust, proven design where field errors within a 2-meter long undulator section can be handled adequately with standard shimming techniques. Furthermore, economies of scale are advantageous for ensuring that periodicity in each of the ~50 sections is uniform. Alignment between sections via the beam-based technique with variable electron energy proposed should provide adequate trajectory control. In summary, the hybrid technology makes for a “vanilla” LCLS design that adequately does the job.

A new undulator team from Argonne is now on-board and is reviewing the previous SSRL team’s technology selection and design. The new team wishes to revisit the selection with the stated motivation being to see if the envelope on safety/margin can be pushed back. In particular, they have some concerns regarding quadrupole mispositioning. The TAC notes that in-situ quadrupole position adjustability is actually a very desirable horizontal/vertical corrector feature that is incorporated into the present design. An alternative superconducting helical option is attractive to the Argonne team. (And also to the SSRL team, but was rejected because it was thought to be costly, complicated, difficult to hold to mechanical tolerances, and to provide with steering corrections.) This helical design has the advantage of a shorter gain length, reduced spontaneous radiative power, and a relaxed pipe size requirement.

The TAC notes that it is appropriate for the new team to have a 6-9 month buy-in period. It is also noted that development of the superconducting undulator technology is important for long-term next generation IDs and rings. Still, the new team needs to rapidly bring the superconducting helical conceptual design and test plan to an equal footing with the hybrid baseline strawman or else drop it, since carrying various undulator options past next Spring would be at odds with the philosophy of a focussed program. An evaluation of perceived superconducting technology risks versus benefits/advantages over the conservative hybrid baseline strawman design, coupled with considerations of (1) x-ray optics implications, (2) resource allocation, and (3) the strategic issues discussed in the overview can form the basis for an informed management decision regarding LCLS technology choice next Spring.

Some helical superconducting undulator technology issues the TAC would like to see addressed include: risk of superconducting technology to undulator performance, tolerances and tuning of this coil dominated helical design, dimensional stability during cool-down, alignment and accessibility, mis-steering during a quench, and cryogenic details.

For the next TAC meeting it would be appropriate to hear about (1) the new team’s views on the baseline design details, their buy-in of details, and any proposed modifications, (2) the baseline (hybrid) prototype development and test plan, (3) LEUTL design and results, and (4) the superconducting helical strawman option conceptual design and prototype plan.

E. SIMULATIONS (Bill Colson, Naval Postgraduate School)

Computer simulations have been a powerful tool for FEL development and understanding for decades. SLAC needs a focussed code development program with milestones to get established EEL codes, like FRED-3D and GINGER, modified for LCLS simulations. The priorities of various added features should be established at the September 1999

Workshop on LCLS code development. LCLS should assign adequate resources to this important research project component.

Benchmarking and validation of the codes with experiments like VISA are educational and valuable, but the codes are quite mature and have been used successfully for many years. The major problem in applying the codes to experiments is that physical input data are not known with sufficient precision. An important ingredient is the initial electron beam distribution function. Emittance and energy spread values describe the overall width of distributions in phase-space, but the shape of the distribution is often not known. In a high gain EEL, like LCLS, theoretical and experimental work has shown dramatic dependence of the beam distribution shape.

It is suggested that EEL simulations be used to evaluate the sensitivity to key parameters like emittance, peak current, energy spread, etc. Some of this has been addressed in the 1998 LCLS Design Review, but curves showing (i) the x-ray power and (ii) the x-ray spectrum versus emittance, peak current, energy spread, etc. give a clear impression of how much degradation in performance results from variations around the design goals. The sensitivity to beam quality and other parameters is important for TAC decision making and priorities.

An important recommendation of the TAC is to consider the scientific case for operating LCLS with less than saturated power. Since the details of the scientific case are still evolving, there is no clear reason at this point to demand that LCLS reach saturation. Without saturation shot-to-shot x-ray fluctuations are larger and the x-ray spectrum is broader. But, the scientific applications have not provided a necessary standard for power and coherence. The scientific users have made it clear that short wavelengths, like 1 Angstrom, are important, but statements about power and coherence have not been quantitative. Since the LCLS is providing many orders of magnitude improvement in the area of peak power and coherence, it may be prudent to consider reduced performance goals such as cutting back on peak power and coherence instead of operating at longer wavelengths than I Angstrom. This may be cast as a backup plan, but if there are interesting scientific experiments that can make use of less than “amazing” power and coherence, it may provide a better developmental path. Fix the wavelength, and continually improve coherence and power as the LCLS matures.

It is important to avoid over-advertising and to allow time for success so that the users have realistic expectations that are met by the project. To accomplish this, one might propose parameters that evolve during commissioning and these could be accompanied by experiments that make use of the early capabilities of the LCLS. It is important to realize that the route to the final goal may be different than presently envisioned. Planning for this is very important at this stage in order to be able to accommodate different modes of operation within the design. It is evident that the project has already started to do this.

EEL simulations can be used to evaluate design options like the helical, superconducting, electromagnetic undulator compared to the planar, permanent magnet undulator. There are, of course, many issues to evaluate concerning these choices, but simulations can provide sensitivity analysis to beam quality and undulator tolerance as discussed in other parts of this report.

A design option that may be able to improve coherence of the LCLS x-ray beam is to use seeding of the EEL or feedback with a regenerative amplifier. Another source of coherent x-rays may be used to seed the LCLS. The topic of x-ray seeding could provide a collaborative topic between LCLS scientists and the table-top laser community. Another design option proposed is operation at less charge per electron bunch, but better emittance. This is another topic for simulation to address and evaluate.

F. X-Ray Optics (Al Thompson, LBL)

The TAC believes that the highest priority for the x-ray optics group is to define the optical elements necessary for beam characterization. At the next meeting we would like the optics group to fill in the requirements table with preliminary values. In their next presentation, we would like them to describe how these parameters might be measured.

The most critical optical components for the LCLS will be the first optical elements (either mirror or crystal) and the gas cell for attenuating the beam. These components will have to handle the extraordinary power levels that are generated by the machine. The optics group should continue to focus on these components. A good start has been made on the gas cell design. The TAC would like them to also focus on the first optical element and to understand the problems that will need to be solved to achieve an operational device. Detailed design of downstream components (like focusing elements) can be delayed since these components will receive less power and there is rapid development of similar optical components by other groups.

We agree with the plan to select a few possible LCLS experiments and do a strawman design of a beamline for these experiments. This will give the TAC a preview of some of the potential problems with real experiments and enable us to help the optics group define the development plan.

The TAC notes that from the point of view of x-ray optics, VISA’s relevance is limited. One issue that needs to be addressed is that of component survivability.