DOE U.S. LHC Program Office
July 19, 2008

Report on the DOE Review of the U.S. LHC Accelerator Research Program (LARP) and a Presentation of a U.S. Proposal for the Phase-I Accelerator Upgrade in LHC Luminosity

Held at
Lawrence-Berkeley National Laboratory
Berkeley, California
June 19-20, 2008

Report to the Office of High Energy Physics, U.S. Department of Energy

Executive Summary

Our consultants were impressed by the progress of the research conducted within the LARP program. Sophisticated modeling mainly at LBNL has been incorporated into the magnet program to provide guidance for designing, constructing and testing of model magnets. The program now has a stable conductor design that can be used to study magnet behavior, coil variability, and for scaling to accelerator magnet parameters. The accelerator program is achieving good progress in its development of Schottky monitors, chromaticity and tune feedback studies at RHIC; its work on beam-beam wire compensators; and its contribution to hardware commissioning and to the design of new collimation hardware for the initial upgrade in LHC luminosity. However, concern was expressed with the delayed delivery of luminosity monitors to CERN, which was felt to be symptomatic of problems of having a research program taking responsibility for deliverables that should be provided through a formal construction project. In that regard, it was felt that at this time the LAUC upgrade project must be entirely divorced from LARP to assure that it does not impede the important development work that is proceeding within LARP.

The committee was pleased that the LARP program has served as a successful incubator of ideas relevant to the LHC and an effective promoter of U.S. expertise in accelerators, but urged that a separate organization to focus on construction to assure that U.S. contributions to the LHC upgrade are well planned and well executed, and did not interfere with the progress of R&D in LARP. In addition, the panel recommended that more formal discussions and eventual agreements be established with CERN (negotiated through the DOE) that would clarify U.S. responsibilities in any upcoming LHC upgrades. Nevertheless, the committee complimented LARP's effort to contribute to the LHC upgrade and on the advanced status of their plan compared to programs at other non-member states, e.g., Japan.

Introduction

The Large Hadron Collider (LHC) will be a unique facility for basic research that will provide the world's highest energies for probing the structure of matter and the underlying symmetries in the universe through controlled proton-proton collisions over the next two decades. The LHC accelerator, housed in the same 27-km tunnel that previously contained the Large Electron Positron (LEP) collider, has now been completed at the European Laboratory for Particle Physics (CERN) near Geneva, Switzerland, and is undergoing its initial full cool-down. The United States has contributed to the construction of the LHC with in-kind contributions of domestic industrial products and, more importantly, through leading the development of magnetic focusing systems for the four major interaction regions of the LHC ring. In addition, the U.S. is providing substantive support for accelerator instrumentation, beam studies and diagnostics.

To exploit its major investment in the technology and science of particle accelerators, the U.S. initiated the LHC Accelerator Research Program (LARP) to empower U.S. scientists with the means and tools needed to maintain and improve their skills in superconducting magnet design and engineering as well as accelerator physics, commissioning and instrumentation. The scope of the proposed LARP projects includes R&D for an upgraded set of magnets for the LHC interaction regions (IR) to handle an eventual ten-fold increase in luminosity, as well as tasks involving instrumentation, simulation and commissioning of the LHC accelerator. The R&D projects undertaken by LARP are expected to be consistent with the plans envisioned by CERN for the program at the LHC.

A review of LARP was held on June 19-20, 2008 at Lawrence Berkeley National Laboratory (LBNL) by the Department of Energy (DOE). The charge for the review was given in a memorandum from Dennis Kovar to LK Len, on May 14, 2008 (attached as Appendix A). The review covered issues pertaining to the management of the program, commissioning of components of the LHC hardware and beams, instrumentation proposed for the accelerator and development of Nb_3Sn superconducting magnets (see the agenda in Appendix B). In addition, the reviewers (Appendix C) were asked to comment on a proposal presented by LARP for a U.S. construction project to participate in the initial upgrade of LHC luminosity (Appendix D).

Presentations were made by LARP leadership, including progress reports from Level-2 managers (see URL: http://larpdocs.fnal.gov/LARP-public/DocDB/DisplayMeeting?conferenceid=52). The reviewers questioned the speakers during their presentations, and discussed their observations in executive sessions in the presence of DOE representatives Tom Ferbel, LK Len and Bruce Strauss, and Jim Whitmore, an observer from the National Science Foundation. Members of the panel provided both oral and written preliminary findings to LARP management at a close-out session at the end of the review. This report reflects the final conclusions of the consultants proffered in written evaluations sent subsequently to Dr. Kovar.

At the review, Peggs introduced Eric Prebys of Fermilab, the recently appointed leader of LARP to the committee. Prebys participated fully in the discussions at the review, and indicated that he

will be at CERN for the anticipated tests of the LARP luminosity monitors, and assured the committee that the product will be delivered to CERN for its next run.

The discussion in the rest of this document, based on the written reports of our consultants and presentations made by LARP management, provides additional information on the views and recommendations offered by our committee of experts.

Findings

LARP proponents described the technical progress made in the development of accelerator and magnet systems during the past six months. The quality of the presentations and the overall responsiveness of the LARP team to questions and challenges were deemed quite satisfactory. The presentations emphasized the constructive cohesiveness and smooth coordination of the different LARP research efforts across the laboratories.

The magnet program continues to achieve its milestones – both in the sophisticated level of modeling of magnet structures and beam interactions, as well as in constructing and testing of model magnets. The growing integration of detailed modeling of magnet systems, including stresses and thermal performance, and comparisons to data, provides important insight into directions for further study and development, and offers confidence in the results of further extrapolations. The proponents discussed the value of their current LARP strategy of using long quadrupole (LQ)[†] magnets to learn about their scaling in length, and the high-field quadrupole (HQ)[‡] magnets to demonstrate ultimate accelerator quality. Two basic mechanical structures ("collar" and "shell") have been shown to be suitable for scaling up to accelerator-class interaction region (IR) magnets. Also, the design of the baseline Oxford Type 54/61 conductor is now well-established for continuing the ongoing magnet activities. With the successful implementation of instrumentation and analysis tools, LARP has made quantitative interpretation of complex magnet performance possible. Currently, coil variability appears to be the main remaining issue in scaling to a 4-meter long LQ. Previous technology quadrupole (TQ)[*] models and the long racetrack (LR)[◊] dipole-magnet efforts could not sort out the problem of coil variability because of limited ability to repeat tests.

Presentations in the accelerator instrumentation area also indicated good synergy among U.S. accelerator groups participating in the LARP programs. Significant progress has taken place in several critical areas. The Schottky monitors and the associated front-end electronics were successfully delivered. The world's first simultaneous tune and coupling feedback system was developed within the LARP program, and is now evolving into a chromaticity-tracking system.

[†] The main goal of the LQ effort is to demonstrate the capability to scale up to 3.6 m lengths of magnets in a design configuration directly relevant to the luminosity upgrade of the LHC IRs.

[‡] The HQ magnet has large aperture (~130 mm) and 15 T coil peak field. It is designed to explore the performance limits (field/stress) to determine the design space for a possible future Phase-II LHC upgrade. It is also suitable for upgrading the Phase-I quadrupole with greater design/operating margins.

[*] There are two types, the "shell" and "collar" design denoted as TQS and TQC. The goal of the two TQ series (TQS and TQC) was to achieve 200 T/m gradient in a 90 mm aperture, using a cos (2θ) coil configuration. The two model series use same coil design but different support structures: TQS has a shell-based structure derived from the LBNL high field dipole program, TQC has a collar-based structure derived from the NbTi quadrupoles developed at FNAL for LHC IRs.

[◊] The LR dipole magnet, 3.6 m long, was intended as a technology demonstration of the ability to fabricate long accelerator-type Nb_3Sn magnets. The support structure is similar to earlier sub-scale magnets (SM series), thus it provides a demonstration of the scalability of this structure to long lengths.

The feasibility of an AC dipole has been demonstrated. By putting a perturbation on the beam, it permits fast measurements of important beam parameters during LHC commissioning. The low level radio-frequency (LLRF) control system development is proceeding well based on technologies developed at PEP-II. LARP travel funds have leveraged this SLAC contribution to LHC beam instrumentation. The reviewers expressed disappointment in the delay of ~12 months in the delivery of the luminosity monitors to CERN, which may be an indication of an organizational/management weakness in the current LARP model. The work on rotatable beam collimators is continuing and the design appears ready to go, but CERN's goals, requirements and overall schedule are unclear. Other accelerator topics including electron cloud, beam-beam simulations, electron lenses, crystal collimators and crab cavities, potentially important to the LHC, have been included in the LARP program.

The LARP team took responsibility for sorting out and presenting potential projects for the U.S. proposal for the Phase-1 LHC accelerator upgrade. The proposed beam separation dipoles, based on RHIC dipole magnets, comprise the largest single part of the U.S. project, and were presented by LARP as a cost-effective and solid U.S. contribution.

Comments

LARP research in Nb_3Sn magnets is regarded as one of the most important developments in U.S. accelerator technology. The panel felt that LARP has been highly effective as an incubator of new ideas. The research activities, which leverage U.S. expertise, were found to be interesting, relevant, and professionally executed. Our consultants were very pleased with the excellent technical progress made both in accelerator systems and in magnet development.

Although in general the reviewers were impressed by the overall performance and status of the LARP program, they also expressed concern over certain issues. For instance, it was noted that although coordination among U.S. laboratories is seamlessly cohesive, LARP's relationship with CERN, as result of its ad hoc arrangement, is potentially problematic. The research planning of LARP and of CERN appear to be somewhat disjointed. Also, while LARP functions very well as a research initiative, it is less effective in providing hardware contributions to the LHC. There is additional concern that the selection of LARP research topics is a process that lacks sufficient transparency and clear prioritization. Despite the lack of firm specifications and statement of clear needs from CERN, the panel commended LARP for taking this action on behalf of the U.S. accelerator community.

The quench limits found in recent studies of 1m magnets often appeared lower at 2K than at 4.2K temperatures, which is puzzling. The reviewers identified coil variability in the fabrication/manufacturing process as a great concern. The reviewers also felt that if LARP research activities were not properly prioritized, there would not be sufficient resources available to study the issue of coil variability in detail, which could adversely impact the HQ effort to achieve accelerator-quality magnets.

The LARP accelerator program consists of many diverse activities, and, as indicated above, the transparency of the process that leads to the selection topics for research is a concern. A more minor, but still important concern is the possible radiation damage to the insulating material (MACOR) used in the argon ionization chambers of the luminosity monitors. The failure to have delivered the luminosity monitors to CERN on time reflects poorly on LARP's reputation, and certainly points to a potential weakness in the LARP system. The lack of concrete mutual understandings between CERN and LARP for its accelerator components, such as the rotatable collimators, is also of some concern in that all the excellent development work may not be implemented in the LHC.

The review panel pointed to potential adverse effects of LAUC on the LARP research program, if the two activities do not have separate and independent management. There was also universal concern among the reviewers in the lack of a clear protocol between U.S. and CERN regarding the LHC upgrade.

Recommendations

The recommendations from the review panel can be divided into the following four areas discussed in the above sections.

LARP Organization and Management

Concerning general and administrative aspects, the reviewers recommended that LARP should:

1. Establish a more strongly-coupled and transparent relationship with CERN management to assure that CERN buys into all formal LARP commitments. Should CERN judge any specific development item suggested by LARP as inappropriate for future application at the LHC, LARP should drop that research activity and move on to another high priority activity. In the case the dropped activity appears promising, it should be recommended for continuation elsewhere within the OHEP accelerator R&D program.
2. Manage and fund LARP efforts adequately to ensure the successful completion of any research development that becomes an item to be delivered to CERN. Under such circumstances, any required construction should then be managed as a separate project.
3. Devise a clear and open system to prioritize LARP research topics according to merit and the goals of its mandated program.

LARP Magnet Program

For the magnet program, the panel recommended that LARP:

1. To ensure a reproducible manufacturing process, a single conductor and structure-type should be adopted to determine and quantify the effects of coil variability on magnet performance. This effort should be based on Oxford Type 54/61 conductor and the shell-type structure for testing LQ magnets.
2. At this juncture, restrict the use of more advanced conductors (such as Oxford Type 108/127) to tests involving short technology quadrupoles (TQ).
3. Complete an accelerator-quality magnet design (HQ) as soon as possible, focusing on operational stability with a 2K temperature margin (with all loads).
4. Should give priority to MCNPX-type of simulation of radiation effects over the work on decreasing the diameter of strands (D_{eff}).

LARP Accelerator Program

The Panel's recommendations for the overall U.S. accelerator program are:

1. Establish more formal coordination with CERN to formulate U.S. goals, requirements and schedules.
2. Perform more radiation-hardness tests on the insulating material (MACOR) that is being used as standoffs in the Argon ionization chambers and verify that it is, in fact, suitable for the doses foreseen in the luminosity monitors.

LAUC Proposal

The review panel heard a presentation of a proposal for a U.S. LHC accelerator upgrade project, LAUC. Its recommendations are as follows:

1. The support and budgets for LAUC should be independent of projected LARP funding, and LAUC activities should not interfere with the LARP research program.
2. Set up a project management structure for LAUC, perhaps by establishing an office at an appropriate host laboratory, and appoint a full-time project manager under requirements that conform to DOE standards.
3. Establish a new protocol with CERN to define the U.S. role and the process for selecting projects and the means for interactions among the DOE and CERN communities.
4. The upgrade-construction project should define and provide ways to control delivery schedules and the budgeting process, and it should draw from LARP and from the wider U.S. technical community ways to formulate and establish an intensive reviewing mechanism that is coordinated with CERN. For instance, the current selection of LAUC projects is deemed reasonable; nevertheless, it is unclear what CERN needs and desires.
5. Ensure that small changes in design of the proposed beam separation dipoles do not introduce unforeseen problems, even though they are based on RHIC dipoles.
6. Perform a technical review on the cryogenic feedbox design to ensure that proper choices are made.
7. Change the acronym for "LAUC" to make it distinguishable from "LARP," as spoken in "international English."

Appendix A – Charge Letter

Department of Energy
Office of Science
Washington, DC 20585

May 14, 2008

MEMORANDUM FOR LK LEN
LARP PROGRAM MANAGER
FACILITIES DIVISION
OFFICE OF HIGH ENERGY PHYSICS

FROM: DENNIS KOVAR
ACTING ASSOCIATE OF SCIENCE
FOR HIGH ENERGY PHYSICS

SUBJECT: U.S. Large Hadron Collider Accelerator Research Program Annual Technical and Management Review

This memorandum is to request that you organize and conduct a Technical and Management review of the U.S. Large Hadron Collider (LHC) Accelerator Research Program (LARP). This review should appropriately involve the input and participation of related programs in the Office of High Energy Physics.

The LHC Accelerator Research Program, encompassing research and development activities in superconducting materials and magnets, accelerator systems, beam instrumentation, and LHC accelerator commissioning efforts, plays an important role in the nation's high energy physics program as it undergoes a transition to participate in experiments at the LHC at CERN. It is important for the Office of High Energy Physics to understand the progress and future plan of the research program, the effectiveness of its management and whether resources and planning are being directed optimally to support the scientific goals of the nation's high energy physics program.

It is requested that your review evaluate:

- The quality and significance of the LARP scientific and technical accomplishments, and the merit, feasibility and impact of its planned research program;
- The effectiveness of management in strategic planning, developing appropriate core competencies, implementing a prioritized and optimized program for potential participation in future accelerator upgrades at the LHC at CERN;
- The effectiveness and appropriateness of the laboratory interactions to maximize the leveraging of existing infrastructure and expertise available at those laboratories.

In the context of these general review criteria there are special circumstances that the nation's high energy physics program is facing where additional information at this time would be helpful

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for this office in its planning. In particular, what is the appropriate level of participation for the LHC upgrades which may include superconducting magnet and accelerator systems components, what is the timeline and the resources needed to mount this program, what are the scientific and technical risks associated with the proposed program, and are the available resources for LARP being optimally used to achieve the planned goals.

The review should also comment upon what progress has been made towards addressing action items, if any, from previous LARP Reviews.

I would appreciate receiving the review reports, suitable for transmission to the laboratories, within 45 days after the review.

cc: Steve Peggs, BNL
Michael Procario, SC-25
Bruce Strauss, SC-25
Tom Ferbel, SC-25

Appendix B – Agenda for Review of LARP June 19-20, 2008

LARP DOE Review Agenda

Lawrence Berkeley National Laboratory

June 19-20, 2008

Thursday June 19

		Plenary 1: LARP OVERVIEW	Room 1
830	30	Executive session	
900	60+15	Overview: LARP status and issues	Peggs
1015	15	*Coffee break*	
		Parallel 1: MAGNET SYSTEMS	Room 1
1030	30	Model quadrupoles	Sabbi
1100	30	Long quadrupoles	Ambrosio
1130	30	Materials	Ghosh
1200	45	*Working lunch*	
1245	60	Discussion	All
		Parallel 2: ACCELERATOR SYSTEMS	Room 2
1030	30	Instrumentation	Ratti
1100	30	Accelerator Physics	Fischer
1130	30	Collimation	Markiewicz
1200	45	*Working lunch*	
1245	60	Discussion	All
		Plenary 2: LARP SUMMARY, LAUC OVERVIEW	Room 1
1345	30+10	Summary: Magnet Systems	Wanderer
1425	30+10	Summary: Accelerator Systems	Markiewicz
1505	15	*Coffee break*	
1520	40+15	Overview: LAUC status & issues	Peggs
1615	120	Executive session	
1815		Adjourn	
2000		*Dinner*	

Friday June 20

830	60	Response to questions posed by committee	
930	30	Executive session	
		Plenary 3: LAUC	Room 1
1000	25+5	Beam separation dipoles	Wanderer
1030	25+5	Feedboxes & systems engineering	Lamm
1100	15	*Coffee break*	
1115	25+5	Collimators	Markiewicz
1145	25+5	Advanced instrumentation	Ratti
1215	45	*Working lunch*	
1300	180	Committee discussion and preparation for closeout	
1600	15	CLOSE OUT	Room 1
1615		Adjourn	

Appendix C – List of Consultants

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Appendix D – LUAC Proposal