

**Report on the DOE Review
of the
U.S. LHC Accelerator
Research Program (LARP)**

Held at
Fermi National Accelerator Laboratory
Chicago, Illinois
July 15-16, 2010

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

Executive Summary

The review committee was impressed by the accomplishments and the quality of work performed under the LARP program—the Accelerator Systems (AS) has delivered all instrumentation to the Large Hadron Collider (LHC) at CERN as promised; the Magnet Systems (MS) has successfully matured the conductor design for Nb₃Sn quadrupoles with the achievement of its technical objective for the long quadrupole (LQ); and LARP Management has run a very successful program with all the collaborating laboratories working together effectively and efficiently.

LARP has made significant contributions (startup, commissioning, and operation) to the achieved successes of LHC. CERN has expressed their appreciation for these contributions, noting that the US LARP team is an integral part of the LHC accelerator program. The Long Term Visitor and Toohig Fellows programs are viewed by CERN as very attractive and successful, and benefit the US program. Many of the LARP activities have significant application to present and future accelerator R&D confronting US accelerators. The Chamonix meeting has redirected the course of LHC accelerator upgrades and improvements for the next decade, resulting in a course for accelerator R&D that is now more strategic and is dependent on LARP activities.

All the instrumentation delivered to CERN by LARP is working well. CERN is interested for the LARP AS team to pursue instrumentation in support of the LHC injector chain, as expressed in Chamonix. The first prototype rotatable collimator is due to be shipped to CERN in September 2010 for installation in the SPS during the December 2010—January 2011 shutdown. Crab cavities, championed by LARP, are now part of CERN's baseline planning for the Phase-II luminosity upgrade.

The LARP MS program is the world's leading effort in Nb₃Sn SC magnets for accelerators. The LQ fabrication and testing has demonstrated the robustness of the LARP design in the transition from short model magnets to long magnets and the >200 T/m achievement is a major milestone. The High-field Quadrupole (HQ) program is now in full swing, with two magnets built and each undergone two cycles of assembly, testing, and re-assembly. The insulation failure in HQ2 is now under investigation. The new luminosity upgrade strategy, in response to the Chamonix 2010 LHC meeting, foresees a Technology Selection in 2013-2014, for which a Long HQ quadrupole must be built and tested. However, the specifications for that LHQ magnet and the criteria for the selection have yet to be articulated.

The Committee listed a number of recommendations for the LARP program. The key recommendations are as follows:

- Accelerator Physics—perform simulations in the coming year to help guide CERN's choice of quadrupole aperture
- Crab Cavities—work with CERN to develop clear specifications and a realistic R&D plan with goals for the crab cavities;

- Magnets—undertake, in close consultation and cooperation with CERN, a substantial role for modeling energy deposition and radiation damage from beam losses and other collider issues related to the IR quad aperture decision; and
- LARP management—develop a strategic plan for LARP R&D that supports the LHC schedule, and meets the FY11 budget; and work with DOE and CERN to establish a formalism for the dialog and protocol which will provide the needed specifications in time to meet agreed upon milestones.

Introduction

After the initial delay to repair some of its superconducting magnets, the 27 km Large Hadron Collider (LHC) at the European Laboratory for Particle Physics (CERN) near Geneva, Switzerland, is now operating at the world's highest collision energies. It is a unique facility for basic research in high energy physics to probe the structure of matter and the underlying symmetries in the universe through controlled proton-proton collisions. The United States has contributed to its construction with in-kind contributions for the magnetic focusing systems at the four major interaction regions of the LHC ring. In addition, the U.S. has and is providing substantive support for accelerator instrumentation, beam studies and diagnostics.

To maximize the science exploitation from its major investment in the technology and science of particle accelerators, the U.S. initiated the LHC Accelerator Research Program (LARP) to develop the tools and technology for improving the performance of the machine. This also serves to maintain U.S. core competency in accelerator technology in the areas of superconducting magnet design and engineering as well as accelerator physics, commissioning and instrumentation. The R&D projects undertaken by LARP are expected to be consistent with the plans envisioned by CERN for the program at the LHC.

The charge for the annual program review of LARP was given in a memorandum from Dennis Kovar to LK Len, on May 27, 2010 (attached as Appendix A). The review, chaired by LK Len, was held on July 15–16, 2010 at Fermi National Accelerator Laboratory (FNAL) by the Department of Energy (DOE). The review covered issues pertaining to the management of the program, various accelerator R&D activities, operation of components of the LHC hardware and beam instrumentation delivered by LARP for the accelerator and development of Nb₃Sn superconducting magnets (see the agenda in Appendix B). The list of reviewers is included in Appendix C. The reviewers were asked to 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; specifically, are these LARP activities well aligned with present LHC schedule;
- The effectiveness and appropriateness of the laboratory interactions to maximize the leveraging of existing infrastructure and expertise available at those laboratories.

In addition, they were also asked to comment on the priority and levels of R&D effort for LARP to undertake in the superconducting magnet and accelerator systems that would be most effective and optimum in positioning the U.S. for participation in the planned LHC upgrades and also is the multi-year plan developed by the LARP management consistent with this goal, 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.

Presentations made by LARP participants can be found at the LARP review webpage: <http://indico.fnal.gov/conferenceOtherViews.py?view=standard&confId=3363>. At the review, the committee questioned the speakers during their presentations and discussed their observations in executive sessions in the presence of DOE representatives Michael Procario, LK Len and Bruce Strauss. 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.

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

The review committee (see Appendix C) heard technical progress reports presented by the LARP participants in the development of accelerator and magnet systems during the past year. The presentations were of high quality and the overall responsiveness of the LARP team to questions and challenges was deemed satisfactory. The presentations showed a strong cohesiveness and smooth coordination of the different LARP research efforts across the laboratories. There were also two talks by the CERN collaborators on the LHC schedule and upgrade plan.

The reviewers found that the LARP activities under the Accelerator Systems to be noteworthy. These include beam instrumentation, low-level radio-frequency (LLRF), crab cavities and accelerator physics. All accelerator instrumentation was delivered to CERN as promised and is working well. CERN representatives at the review stated that LARP contributions to LHC startup, commissioning, and operation have been extremely valuable.

The Chamonix meeting has resulted in significant rethinking and redirection of LHC upgrade paths and priorities, which in turn is affecting LARP priorities. Crab cavities, championed by LARP, are now part of CERN's baseline planning for the Phase-II luminosity upgrade. CERN considers crab cavities essential in the luminosity upgrade foreseen for 2018-2020. CERN is also enthusiastically pursuing critical US contributions for instrumentation in support of the LHC injector chain. The refocused upgrade path now includes superconducting magnets, crab cavity development, superconducting links, phase 2 collimator, SPS-related upgrade, hollow electron lens as a primary scraper, and support for the upgrade studies for the PSB.

The prototype rotatable collimator is due to be shipped to CERN in September 2010 for installation in the SPS in the Dec2010/Jan2011 shutdown. A significant amount of technical work and verification remains to be done before the device can be shipped. The collimator will be tested in the SPS, with final testing, potentially to destruction, to be done in the CERN Hi-Rad-Mat facility when it becomes available. It should be noted that the LHC has a 3-phase collimation plan: the initial collimation system in 2009-2011 (insufficient to handle design luminosity), an interim system to be installed in the 2012 shutdown for 2013-2015 running, and the full system after the 2015/2016 shutdown.

Electron cloud study is ongoing and it is driving the design of the LLRF feedback system in SPS. Relevant experiments are being pursued with focus on the goal of defining the SPS feedback system. A wideband (GHz, stripline kicker) feedback system to control E-cloud and transverse mode coupling instability (TMCI) effects in SPS and LHC is being considered. Accelerator physics simulations have been performed in support of LARP activities as RHIC and Tevatron are being exploited to perform beam studies. Hollow beam/lens is now considered for collimation.

Within the LARP Magnet Systems, it was found that the Technology Quadrupole (TQ) magnet program has demonstrated the viability of the mechanical, electrical and conductor design for Nb₃Sn quadrupoles, and validated the LARP design philosophy for most of the important elements of magnet technology: the superconducting strand, the cabling, the insulation, the management of stress within the quadrupole structure, quench protection.

The Long Quadrupole (LQ) fabrication and testing has demonstrated the robustness of the LARP design in the transition from short model magnets to long magnets, which had remained until now a question mark. The quality control during coil fabrication has coupled well with repair of the few faults detected, and disassembly and reassembly has been accomplished with recovery of full performance. The LQ success has been a major milestone for Nb₃Sn magnet technology and is a signal achievement of LARP during the past year.

The High-field Quadrupole (HQ) program is now in full swing: two magnets have been built and each has undergone two cycles of assembly, testing, and re-assembly. A catastrophic insulation failure in HQ2 occurred recently. Work has begun to study the causes of the failure so as to understand and remedy those causes in the design or in the fabrication procedures. This effort is the highest priority of the LARP team and is being treated that way.

The new luminosity upgrade strategy, after the Chamonix 2010 LHC meeting, foresees a Technology Selection in 2013-2014, for which a Long HQ quadrupole must be built and tested. However, the specifications for that LHQ magnet and the criteria for the selection have not yet been articulated. The target for installing a full complement of Nb₃Sn quadrupoles in 2018-2020 will require an ambitious transition to a manufacturing project very soon after the Technology Selection. The infrastructure may require lead times that reach almost back to the present.

The reviewers noted that all the collaborating laboratories under the LARP Management are working together effectively and efficiently. The Program Management activities, which include commissioning at the LHC, and the Long Term Visitor and Toohig Fellowship programs, were found to be valued highly by CERN. LARP has made significant contributions to help achieve the successes at the LHC. The CERN representatives at the review acknowledged and expressed their appreciation for these contributions, and notes that the LARP team is an integral part of the LHC accelerator program. The Chamonix meeting has redirected the course of LHC accelerator upgrades and improvements for the next ten years, resulting in a course for accelerator R&D that is now more strategic (with five new task forces) and is dependent on LARP activities.

Comments

The reviewers found the overall accomplishments in the LARP program to be very impressive. In the Accelerator Systems, they were especially impressed by the completion and delivery of all instrumentation to the LHC with all systems working well. The development of the fast kicker technology for e-cloud control is interesting and potentially useful in many other applications. The reviewers saw a need for developing detailed technical and safety requirements for installation of the rotatable collimator in the SPS and for evaluating performance of the device. These requirements should be clearly stated and formally agreed upon by LARP and CERN. Pass/fail criteria in the Hi-Rad-Mat test also need to be very clearly specified before proceeding with the test. The first prototype rotatable collimator appears to be extremely complex. The reviewers therefore encourage LARP to pursue in parallel alternatives that are less complicated and have the potential of greater reliability. The main goal of the crab cavity activities at this time appears to be prototyping to validate the crab cavity design.

The recent failure of the HQ2 magnet raises an urgent need to understand its origins and modify design or fabrication to remedy them. While such failures are part of the R&D, the team is responding with urgency. There is also an urgent need, in lights of the new CERN strategy after Chamonix 2010, for a dialog between LARP and CERN to reach specification on the requirements for LHQ and the criteria for the Technology Selection. The longer-term effort towards a magnet construction project following a successful Technology Selection requires that infrastructure needs for manufacturing long magnets be addressed soon, if not at this time. The reviewers support the plan proposed by LARP to include the infrastructure for 10 m magnets in the budget and planning for the construction for LHQ beginning this year. As the only group that perfected Nb₃Sn technology, it is essential that LARP magnet group recognize that it is now in a new phase, where a pre-project build-up of the infrastructure for winding, potting, reacting and assembly of the final magnets and design for reliability become a major part of their task. The reviewers also suggested testing and potential phase-in of the Titanium Doped Superconductor.

There are a number of technical issues remain to be addressed in the magnet program, and are embodied in LARP's agenda for the coming year. The reviewer highlighted the importance of developing an understanding of the delamination regions on the inner windings that seems to follow repeated quenches because such delamination could be particularly troubling for quench protection in superfluid helium since SFHe would fill the void region and thermally decouple inner quench heaters from the windings.

There appears to have been no action on the suggestion from last year's review, where it was suggested that the Accelerator and Magnet teams cooperate to model the aspects of operation of the IR quadrupoles in the luminosity upgraded LHC as required to inform the analysis of the aperture requirements. CERN's present view on this is that a decision on aperture should await LHC operation with 7 TeV beams. Given the foreseen schedules for 7 TeV beam operation (>2015) and installation of the IR upgrade (2018-2020) the two timings would likely be inconsistent.

The review panel commended the LARP Management for establishing a well run program which is impacting the LHC and bringing benefit to accelerator R&D in general. Its collaborating laboratories are working effectively and efficiently with each other. Recommendations from the last review were adequately addressed except the magnet aperture recommendation which is repeated this year. It was noted that LARP is an R&D program, and was not established to build and deliver hardware, so additional rigor is needed within LARP to clearly define the end of the R&D phase, to decide when to move into a production (or project) phase, and to delineate funding between the two activities. This is particularly relevant to infrastructure development. There is also a need for better articulated specifications and deliverables for each R&D item. These need to be determined by the LHC task forces in time to meet the LARP technology decisions. Given the constrained funding available in FY11, it is important to prioritize R&D tasks and fund those with specific and high visibility technology deliverables.

Recommendations

Several recommendations have been provided by the review panel in the three areas of the LARP program as discussed in the above sections.

LARP Accelerator Program

The Panel's recommendations for the overall LARP accelerator program include:

For crab cavity—

1. Work with the CERN-RF Group to develop clear specifications and a realistic R&D plan with goals for the crab cavities.
2. Prepare a technical design report with clearly-defined roles, responsibilities, schedules, and costs.
3. Subject the R&D plan and goals to a peer-review in 2011.
4. Write and submit a proposal to DOE on crab cavities prototyping.

For Accelerator Physics—(same as last year)

1. Perform simulations in the coming year to help guide CERN's choice of quadrupole aperture.

LARP Magnet Program

For the magnet program, the panel provided the following recommendations:

1. The panel **strongly** recommends that, during the coming year, in close consultation and cooperation with CERN, LARP undertake a substantial role for modeling energy deposition and radiation damage from beam losses and other collider issues related to the IR quad aperture decision.
2. LARP/APUL magnet program should initiate an aggressive request for funding to respond to the pre-project stages of the LHC Upgrade Project recently defined at Chamonix.
3. LARP should request a letter from CERN to DOE stating that Nb₃Sn Technology is the primary candidate for Interaction Region Quadrupoles of LHC Upgrade Project.
4. Establish a dialogue with CERN to address and settle the quadrupole length question, then prepare a detailed proposal to DOE for a long quadrupole project.
5. DOE should develop a protocol such that requests for collaboration, that are out of the existing list of LARP projects, such as the DS and D1 magnets as outlined by Gijs de Rijk at this review, can be responded to.
6. Collaborate with cognizant CERN experts to develop a plan for material selection and testing that can be executed when the CERN comprehensive testing facilities become available.

LARP Organization and Management

The review panel has two recommendations for the management and organization aspects of LARP:

1. Develop a strategic plan for LARP R&D that supports the LHC schedule, and meets the FY11 budget. Present to DOE by March 15, 2011.
2. Work with DOE and CERN to establish a formalism for the dialog and protocol which will provide the needed specifications in time to meet agreed upon milestones.

Appendix A – Charge Letter



Department of Energy
Washington, DC 20585

May 27, 2010

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

FROM: DENNIS KOVAR
ASSOCIATE DIRECTOR 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 (OHEP).

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 begins to participate in experiments at the LHC at CERN. It is important for OHEP 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; specifically, are these LARP activities well aligned with present LHC schedule;
- 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 for this office in its planning. In particular, what should be the priority and levels of R&D effort



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for LARP to undertake in the superconducting magnet and accelerator systems that would be most effective and optimum in positioning the U.S. for participation in the planned LHC upgrades; and is the multi-year plan developed by the LARP management consistent with this goal? What is the timeline and the resources needed to mount this program? What are the scientific and technical risks associated with the proposed program? 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.

Sincerely,



Dennis Kovar
Associate Director of Science
for High Energy Physics

cc: Eric Prebys, FNAL
Michael Procario, SC-25
Bruce Strauss, SC-25

Appendix B – Agenda for Review of LARP July 13-14, 2009

	from Thursday 15 July 2010 (08:30) to Friday 16 July 2010 (18:00) US/Central at Fermilab
	<h3>LARP Review</h3>
Description: Annual DOE Review of the LARP Program Click here for information about hotels in the area. Review dinner will be held at the Tango Grill in Naperville at 7:00PM on Thursday. Click here for directions.	
Thursday 15 July 2010 Friday 16 July 2010	
<h3>Thursday 15 July 2010</h3>	
<p>08:30->09:00 Executive Session (closed) (Wilson Hall 3 NW) Description: Executive orientation session</p>	
<p>09:00->10:00 Opening Plenary (Wilson Hall 3 NW) Description: Introductory Session</p>	
09:00 Introduction (20) 	Eric Prebys (<i>Fermilab</i>)
09:20 View from CERN/CERN Schedule (20) 	Oliver Bruning (<i>CERN</i>)
09:40 Upgrade Planning Overview (20) 	Gijs De Rijk (<i>CERN</i>)
<p>10:00->12:20 Magnet Systems A (parallel) (Comitium (WH2SE))</p>	
10:00 Conductor and Cable (30) 	Arup Ghosh (<i>Brookhaven National Laboratory</i>)
10:30 Technology Quadrupoles (TQ) (15) 	Shlomo Caspi (<i>LBNL</i>)
10:45 Coffee (15)	
11:00 Long Quadrupoles (LQ) (30) 	Giorgio Ambrosio (<i>FNAL TDMS</i>)
11:30 High-Field Quadrupoles (HQ) (30) 	Shlomo Caspi (<i>LBNL</i>)
12:00 Discussion (20)	
<p>10:00->12:20 Accelerator Systems A (parallel) (Wilson Hall 3 NW) Description: First Accelerator Systems parallel session.</p>	
10:00 LLRF and electron cloud modeling (20) 	John Fox (<i>SLAC</i>)
10:20 Instrumentation Overview (30) 	Alessandro Ratti (<i>LBNL</i>)
10:50 Coffee (15)	
11:05 Discussion (15)	
11:20 LARP Collimation Program (30) 	Thomas Markiewicz (<i>SLAC</i>)
11:50 Discussion (15)	
12:30 Lunch (1h00)	
<p>13:30->16:05 Accelerator Systems B (parallel) (Wilson Hall 3 NW) Description: Second Accelerator Systems plenary</p>	
13:30 Beam beam modeling and electron lens work (20) 	Alexander Valishev (<i>Fermilab</i>)
13:50 Injector chain (PSB, PS, SPS, and PS2) (30) 	Uli Wienands (<i>SLAC</i>)

- 14:20 Discussion (20')
- 14:40 Crab cavity program (25') ( Slides ) Rama Calaga (BNL)
- 15:05 Coffee (15')
- 15:20 Discussion (15')

13:30->16:00 Magnet Systems B (parallel) (Comitium (WH2SE))

- 13:30 CERN Program and Collaboration (30') ( Slides ) Gijs De Rijk (CERN)
- 14:00 Magnet Systems Summary - Progress and Plans (40') ( Slides ) Sabbi GianLuca (LBNL)
- 14:40 Questions/Discussion (20')
- 15:00 Coffee (30')
- 15:30 Questions/Discussion (30')

16:00->17:00 Plenary Session (Wilson Hall 3 NW)

Description:

Afternoon plenary session

- 16:00 Budget Outlook (15') ( Slides ) Eric Prebys (Fermilab)
- 16:15 Key questions and discussion topics (15')
- 16:30 Discussion (30')

17:00->18:00 Executive Session (closed) (Wilson Hall 3 NW)

Description:

First day closing executive session

- 19:00 Dinner (2h00')

Friday 16 July 2010

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08:30->10:15 Question and Answer Session (Wilson Hall 3 NW)

Description:

Final plenary session with answers to questions from the committee.

- 08:30 Questions and Answers (20') ( Slides ) Eric Prebys (Fermilab)
- 10:15 Coffee (15')

10:30->12:00 Writing Session (closed) (Wilson Hall 3 NW)

- 12:00 Lunch (1h00')

13:00->14:00 Writing session (closed) (Wilson Hall 3 NW)

Description:

Executive writing session

14:00->15:00 Closeout (Wilson Hall 3 NW) ( CloseOut Presentation )

Description:

Closeout Presentations

Appendix C – List of Consultants

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