

Proposed US Contributions to LHC High Luminosity Upgrade

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Executive Summary

In response to the request of the DOE and the recommendations from the 2012 review of the LARP Programⁱ, we are submitting a proposal for US contributions to the high luminosity upgrade of the LHC. This proposal has been arrived at in accordance with our previously submitted down-selection planⁱⁱ. We have determined that the proposed US contributions will be (in order of priority):

1. Half of the cold masses for the 150 mm aperture Nb₃Sn quadrupoles
2. Crab cavity R&D up to the planned tests in the SPS, followed by the construction of the cavities and cryostats for the high luminosity upgrade.
3. Development of a high bandwidth feedback system resulting in a functional prototype.

It appears that these projects can fit within the overall budget guidance given by the DOE, given certain assumptions about contributions from CERN and support from General Accelerator Development (GAD) funds. However, expenses early in the project may require CD-3a earlier than FY17 and/or the commitment of additional GAD funds.

Other projects considered for the contribution package that will *not* be directly supported by LARP are:

- 11 Tesla Dipole: the R&D into this will continue, supported entirely by GAD funds, until a mutually agreed upon stopping point.
- D2 Separator Magnets: This project will be pursued independently by CERN.
- Although it was not one of the candidates in the original document, we have added hollow electron beam halo removal as a possible alternate project, in the event that one of the projects above is not undertaken, if funding increases, or if CERN contributes more to the effort.

These projects can be considered for replacement scope if one of the initial projects turns out not to be viable, or if additional funds become available.

Background

LARP has been coordinating activity at US labs related to the LHC since 2003. Although the program has made numerous contributions to the accelerator, it was always envisioned that R&D done in the

program would lead to a limited number of significant construction projects which the US would undertake to help the LHC reach its highest potential luminosity. Planning for such large projects has not been possible until recently, because of uncertainty in the details of the LHC upgrade, particularly following the 2008 startup incident. Over the last year or so, planning for the luminosity upgrade has been formalized under the HL-LHC design study, and LARP has been integrated into this process through active participation in the HiLumi-LHC Design Study. A key milestone was the choice of 150 mm as the aperture for the Nb₃Sn quadrupoles, which was made in June 2012. This allows us to go forward with detailed planning for quadrupole production.

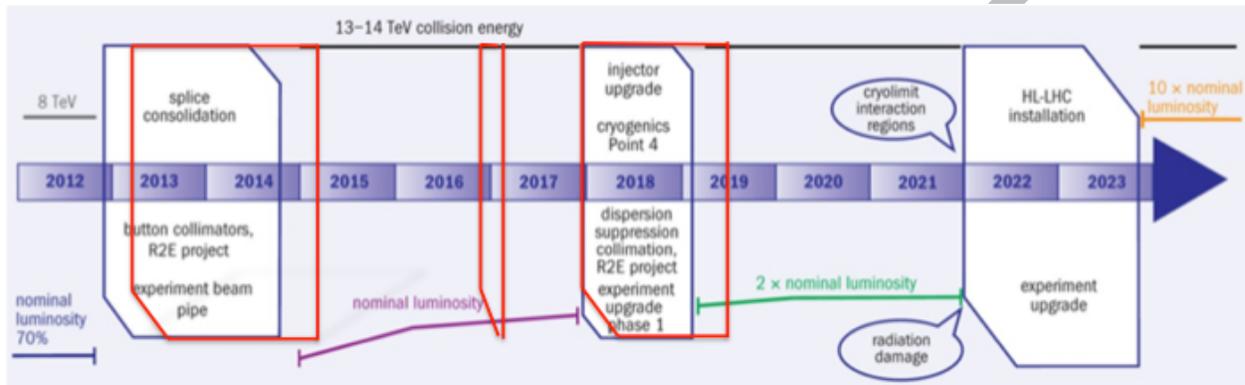


Figure 1 Plan for the next decade, reflecting recent schedule changes. Major upgrade work is done in three long shutdowns (LSs), culminating in LS3, after which the LHC will have a goal of a leveled luminosity of $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$.

Although plans for the upgrade are by no means final, they have progressed to a point where we can begin to plan for the US component. The general schedule for the next decade is shown in Figure 1. Major accelerator work will take place in three “Long Shutdowns” (LSs). The most important upgrades will be the new large aperture quads and likely also crab cavities to compensate for the crossing angle – an effect that becomes much more important at small values of β^* .

Budget Guidance and Assumptions

The guidance that we received from the DOE was to assume flat-flat (\$12.4M/year) LARP funding for FY13 through FY16 and to assume a total project cost (TPC) of \$200M, with CD-3 at roughly the beginning of FY17. This gives a total of \$250M, but we would like to continue to devote some fraction of the LARP money during the next few years to accelerator R&D and personnel programs. The exact split will be discussed shortly, but the total available for the project will be on the order of \$230M.

In addition, the labs have been directed to make available some amount of general accelerator development (GAD) funds to support this effort. The exact amount has not yet been quantified.

We will see that it will be very difficult to launch any of the candidate projects to meet the LS3 schedule if none of the project funds become available until FY17, so we are assuming that some of the project money will be available prior to that time.

Selection Process

Candidate Projects

The candidate scope was discussed at the LARP review in July 2012. Obvious projects within LARP for inclusion were:

- **Final Focus Quadrupoles Based on Nb₃Sn Superconductor.** The R&D leading to these magnets has been the cornerstone of LARP since the beginning. We are nominally proposing to build half of the required cold masses.
- **Crab Cavities.** LARP was an early proponent of crab cavities, and there is hope that the US can contribute to the construction of the cavities for the luminosity upgrade.
- **High Bandwidth Feedback for the SPS.** This is a project to produce a feedback system for the SPS to combat electron cloud and other instabilities. It has grown out of LARP R&D
- **Collimation.** LARP R&D which could *potentially* lead to deliverables includes:
 - The rotatable collimator that has been developed for the last several years by LARP.
 - A halo removal system, using hollow electron beams, a project which was pioneered by LARP, based on studies of electron lenses for beam-beam compensation.
 - Crystal collimators as a replacement for the primary collimators, based on LARP R&D.

The DOE has directed that all significant US contributions to the LHC be coordinated through this project, so we have considered two additional projects, which were initially discussed outside of LARP:

- **11 Tesla Dipoles.** These magnets would be used to free up space in the LHC for collimation, because the high field would allow them to provide the same integrated bend field as one of the existing NbTi magnets with a shorter Nb₃Sn magnet.
- **D2 Separator Magnets.** The D2 magnets are the first twin aperture magnets on each side of the interaction region. As part of the luminosity upgrade, the existing D2 magnets must be replaced with larger aperture versions, still based on NbTi

We initially determined that the collimation projects were not appropriate, since there was no final collimation plan for the LHC; however, because of strong interest at CERN, we have included hollow electron beam halo removal as a possible alternate project in the future.

Cost and Schedule Estimation

We had preliminary cost and schedule information at the review, but it was clear that different standards were used for the different proposals. The first step, therefore, was to use consistent costing methodology for all the projects.

All contacts were given templates with guidance for labor, escalation, and contingency assumptions, and cost estimates were then revised. The updated estimates for cost and schedule are shown in Table 1 along with the proposed CERN contributions.

Prioritization and Selection

Prioritization and selection were done over several meetings of a selection committee, which consisted of:

- Eric Prebys, FNAL, LARP Director
- Tom Markiewicz, SLAC, LARP L2 Manager for Accelerator Systems
- GianLuca Sabbi, LBNL, LARP L2 Manager for Magnet System
- Peter Wanderer, BNL, LARP Representative for BNL
- Lucio Rossi, CERN, Project Coordinator for HiLumi-LHC
- Oliver Bruning, CERN, Deputy Project Coordinator for HiLumi-LHC and LARP Liaison
- Stuart Henderson, FNAL, Head of the LARP Laboratory Oversight Group
- Bruce Strauss, DOE, LARP Program Manager

In addition, Marc Kaducak, FNAL provided project support in the compilation of the cost and schedule. Representatives of the various projects attended the meetings as needed.

Factors considered in the prioritization of the projects included:

- CERN Interest
- Likelihood of being implemented in HL-LHC upgrades
- Exploitation of US expertise

A consensus quickly emerged about the likely scope of the proposal. Considering LARP's history as a leader in Nb₃Sn, it was taken as axiomatic that production of significant fraction of the quadrupole magnets would be given the highest priority. However, the budget guidance does not allow the US to produce all the magnets. The initial proposal is therefore for the US to produce half of the cold masses: those for the Q1 and Q3. CERN would be responsible for the Q2 cold masses, which might have a double length, as well as all cryostats.

The proposed magnet contribution would use up the majority of the budget in the guidance, limiting prospective additional scope. We discussed reducing the magnet contribution to allow for additional activities, but this was not viewed as desirable by either CERN or the DOE.

For the remaining scope, we selected

- Crab cavity work and cryostat development, leading up to the tests in the SPS, with production of cavities and/or cryostats as allowed within the budget
- Development of a high bandwidth feedback system, up to a functional prototype.

It was decided that the 11 Tesla dipole R&D would continue to be supported by GAD funds at FNAL, up to a mutually agreed upon stopping point. Budgeting for that project is not included in our proposal.

After discussion with CERN, we agreed to include hollow electron beam halo removal as alternate scope if circumstances allow or call for it.

BNL is encouraged to finish the magnetic design of the D2 separators, but at this time we cannot pursue them within this project.

All of these are candidates for inclusion if one of the existing projects is terminated or if additional funds become available.

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