US LHC Accelerator Research Program Advisory Committee Review, 17-18 June 2004

Introduction

The Advisory Committee met 17-18 June 2004. Committee members Chao, Devred, Galayda, Ogitsu, Rode, Ten Kate and Wittenberg were present. James Strait asked the Committee to evaluate the planned program with regard to:

- The balance between the breadth of the technical program and the available resources.
- How well the program as a whole and its specific elements address and balance between the two program objectives:
    - To advance high energy physics by helping to make the LHC the strongest possible tool for HEP research.
    - To advance US accelerator physics and technology.

Specific questions were posed, regarding the program components:

Evaluate the plans for participating in machine commissioning, both hardware commissioning and beam commissioning.
Evaluate the priorities and schedules for beam instrumentation development and implementation.
Evaluate the plans for accelerator physics, and how they complement the commissioning and instrumentation work.
Evaluate the proposed collimation R&D program with regard to scientific and technical merit and the match to the LARP goals. LAPAC's advice is a key element in the process for approving program additions to the LARP.
Evaluate the balance between dipole and quadrupole R&D, and between technology development and focused model magnet development.

The Committee acknowledges the high quality of the written proposals and presentations, and commends the presenters for an impressive body of work.

General Response to Charges – Balance between Technical Goals and Resources, Balance Between Two Program Objectives

The Committee consensus was that, overall, the proposed topics for research were important and well-chosen. The balance of emphasis among program objectives was considered reasonable, especially in light of the limited resources available. The committee urges the US LARP participants to make every effort to take advantage of relevant efforts in ongoing research programs whenever possible to make best use of LARP resources. Candidate areas are:

- The study of electron cloud instabilities
- Tune tracker
- Dipole magnet R&D

The Committee felt that, due to limited resources, it was unlikely that the LARP could advance its goals by investing much effort in the large-aperture dipole magnet required for the "dipole first" design, in light of the resource needs of the quadrupole development program.

Machine Commissioning, Hardware and Beam

An important goal of the US LARP program is to establish full-time U.S presence during LHC commissioning, in order to
• Share expertise of commissioning and operating superconducting accelerators
• Commission and train CERN personnel on U.S.-provided instrumentation
• Enhance U.S. accelerator expertise by use of the LHC to perform experiments and test
calculations and theories of fundamental accelerator science.

US-LARP participants will need to develop a thorough understanding of the capabilities and use of the LHC controls system.

The first step of beam commissioning is still solving hardware problems. Therefore CERN needs specialists in operating its major subsystems such as magnets, power, cryogenics, RF, and their controls. US-LARP involvement in the Hardware Commissioning Task should include
• Assistance in installation of US-equipment delivered under the construction
project. (Scope of LARP is focused on US deliverables.)

• Active participation in system commissioning (cryogenic, vacuum, power supplies, etc.)

In the construction Project US responsibility ends with acceptance of deliverables at CERN. LAPAC recommends that the most benefit to US-LARP goals is realized by continued participation in subsequent stages of effort, including installation and equipment checkout. This will

- Assure that US-LARP equipment is installed properly
- Involve US personnel more deeply and productively in the LHC physics program
- Provide US-LARP personnel with a once-in-a-decade experience operating first-of-a-kind accelerator hardware
- Provide CERN with needed help to assure that LHC becomes productive quickly)
- Promote international Cooperation, forging a strong US-CERN partnership for future projects)

The US-LARP hardware installation activity is scheduled to begin with first IR May-July 2005, Continuous throughout FY2006 US-LARP personnel should be present to check installation procedures, participate in first electrical connections, and review electrical and alignment data. Ideally US engineers should be fully responsible for installation of their equipment. US_LARP participants with the appropriate expertise should continue participate through hardware checkout activities and commissioning preparatory activities such as sector testing and injection testing.

Short duration (2 weeks to 2 months) visits by US-LARP personnel are appropriate during fit-up and installation. This short time needs perfect coincidence with CERN schedule.

The next stage of activity is hardware commissioning, the process of bringing all aspects of systems to full operation. This will require specialists with deep knowledge of hardware and software, especially controls. Accomplishment of these goals will require stays of longer duration (up to a year) during hardware commissioning.

The June review presentations did not address the resources required for integration of devices into the LHC control system. This will require significant US-LARP presence (at CERN) to learn about LHC control system.

Once satisfactory performance of the hardware is verified, commissioning activities can address beam physics related to improved performance of the facility. Therefore US-LARP should provide CERN with specialists in

relevant areas of beam dynamics as described in the “Plans for Accelerator Physics” section.

To meet the goals stated above for both engineering and physics activities, US-LARP participants must immediately begin to work closely with CERN specialists understand LHC specific problems. The proposed effort allocation (<1 FTE, 2004- 2006) is insufficient to support the above recommendations.

Ideally, US-LARP should prepare to track hardware performance and analyze problems and equipment failures during commissioning and early operation of LHC. This will require that resources be allocated to more sophisticated remote access to hardware parameters through the controls system. The additional effort during construction will pay off during commissioning and running.

For budget planning purposes LARP can collect valuable information about the real cost of stationing US-LARP personnel at CERN (as well as other important information for planning a stay) from the experience of US-CMS personnel who have already visited CERN.

The commissioning plans presented during this review have emphasized IR Inner triplets. It appears that additional effort will be necessary for collimators, diagnostics, etc. The US-LARP should develop and present plans to cover the full range of commissioning activities, including a realistic estimate of the resources needed.

Priorities and Schedules for Beam Instrumentation Development and Implementation

Tune feedback/feedforward

It appears that plans for LHC tune control will derive considerable guidance from the experience of RHIC, where a similar system is presently being developed and optimized. US-LARP should encourage/enable the preparation of a summary of RHIC experience, with conclusions that can be directly applied to a specification of the hardware need for LHC. It is noted that one difficulty at RHIC is transition crossing, which is not required at LHC.

Chromaticity snap- back is expected to be about ten times stronger than at the Tevatron (~300). US-LARP must define the hardware requirements for

chromaticity snap-back feedback or feedforward correction. Issues to consider are

- How to deal with the bunch-to-bunch variation of this snap-back?
- Is there a way to slow down the initial ramping to make the tune feedback hardware easier?
- How to deal with the coupling effects during ramping and with tune feedback?

Collaboration between LARP and RHIC in general is strongly encouraged. RHIC is an operating cold collider that is transiting from commissioning to improving stages. The 18 month interval when SPS is shut down would be an excellent time for RHIC to invite LHC people interested in:

- electron cloud in a cold environment
- collimation
- optics control in ramping.
- wire compensation

Abort Gap Monitor/Longitudinal Density Monitor

LARP has responsibility for design of a longitudinal density monitor (LDM) to map the current distribution of the LHC beam. LBNL is leading this effort. Electro-optic and laser-mixing techniques for current monitoring are under consideration. This is a very challenging approach. If successful, it would extend the state-of-the art in particle beam diagnostics and provide new insight into longitudinal beam dynamics.

Sensitive, high-bandwidth measurement of the current profile is not among LHC's high-priority requirements for diagnostics. However this device is also expected to serve as an Abort Gap Monitor (AGM), a critical component in the LHC machine protection interlock chain. The AGM function requires a diagnostic which is simple, reliable, and easy to understand and maintain by the resident LHC operations staff. Indeed it should probably incorporate redundant systems for highest reliability. A commercially available gated photomultiplier tube would be an attractive solution to the AGM requirement.

The LDM/AGM task poses some intricate priority questions for LHC and LARP. The LDM would constitute cutting-edge R&D in beam diagnostics, satisfying the second goal of LARP without apparently satisfying the first. The AGM function is crucial to the success of LHC, satisfying the first goal of LARP; however it is perhaps *too* crucial and immediate a problem to be delegated by LHC to LARP. Its priority would necessarily dominate the longer-term LARP initiatives, with corresponding impact on resources. The

LAPAC recommends that LARP seek clarification of the abovementioned issues from LHC:

- Is CERN really delegating responsibility for the critical AGM function to LARP and, if so, does LARP accept this responsibility in spite of limited resources?

- Are the CERN-LHC specifications for the AGM clear, and can they be met with a simple, robust diagnostic?

- Can the AGM and LDM functions be separated?

- If the AGM and LDM functions are separated, does CERN concur with LARP support of the LDM?

Collimation R&D Program

Phase I

Phase I collimation studies are concentrated on comparison of computer predictions to measurements at SPS and RHIC. The presentation to LAPAC demonstrated a comprehensive effort with good balance between modeling and measurement. LAPAC encourages the continuation of this activity and approach. To take best advantage of studies, LAPAC encourages the preparation and use of loss measurement diagnostics associated with collimator studies. Disagreement between model and measurement might be improved by incorporating collimator misalignment in the model.

Phase II

The description of the capabilities and known limitations of the capability of the Phase I absorbers was informative and illuminating. It called attention to some significant limitations of the first-generation absorbers. It seems that "Phase II" collimators might be needed rather early in the LHC operations; furthermore the desired performance of these collimators will pose a formidable challenge to the designers. The proposed strategy is to replace the semi-transparent carbon absorbers with copper/beryllium collimators that will sustain damage from a beam hit. The phase-II collimator design could be based on NLC design concepts. Based on early LHC experience and analysis of the NLC absorber concept applied to LHC, a phase-II upgrade strategy can be chosen.

The manpower estimates for this work seem reasonable. However early installation of the "Phase-II" collimator housings might require too early a

commitment to the housing design. Certainly due attention should be given as early as possible to design of the area near the phase I collimator to minimize radiation exposure to workers installing the phase II hardware when LHC has begun operation.

Lumimonitor

The Luminosity monitor appears to be a sensible design that accounts for and even takes advantage of the harsh environmental conditions in which it must work. Very good progress has been made in testing the monitor with an electron beam at ALS. X-Y resolution of 110 microns has been verified in these measurements.

Excellent progress has been achieved with the allocation of very modest resources. Guidance from LHC suggests that backgrounds should not adversely affect the use of this monitor during normal operations. More information on the expected background would, however, be reassuring to the LAPAC.

Plans for Accelerator Physics, Complement to Commissioning and Instrumentation

Electron Cloud

Electron cloud phenomena are important but still not well understood.

This is an issue for the whole accelerator community, with too many dimensions for LARP to address unilaterally. LAPAC encourages close continued R&D in collaboration with the community at large.

LARP also needs to be more LHC-specific. LARP research should target

- optimal conditioning scenario during commissioning
- definition of e-cloud detector/diagnostics
- cold vs. warm e-cloud conditioning.

The committee strongly endorses the close participation of LARP with LHC -- as is being planned. But it also encourages LARP to actively draw attention and solicit collaboration from the community at large on these more LHC specific items.

The FTE estimate of 0.6 seems adequate/somewhat low.

IR and Beam-Beam Interaction

Shift from design chromaticity due to parasitic collisions, including bunch-by-bunch variations, needs to be estimated.

It may be worthwhile to consider whether IR design alternatives might be identified that are less sensitive to, or more easily protected from magnet glitches and power failures.

Energy deposition calculations are being performed. This work is very important to establishing the engineering requirements of the IR hardware. This work must continue with high priority. Other non-beam-beam and accidental beam loss contributions should also be considered.

The "quad-first" scheme simplifies IR design and is preferred. One disadvantage is the complicated multipole correction in the IR. Another disadvantage is the parasitic collisions. These issues need more attention, although it is noted that the present baseline design has already these complications.

Wire compensation is an interesting and worthwhile effort. Should pursue it actively including doing experiments at SPS (how about Tevatron?). If it works, it can help minimize parasitic collision effects.

The manpower estimate of 2 FTE for 05 and 06 seems reasonable.

Dipole and Quadrupole R&D, Technology Development versus Focused Model Magnet Development

Management, Integration and Funding

Managing the three lab magnet collaboration has always been an interesting challenge. For the LARP this is even more challenging since the base program magnet R&D funding is much larger than LARP's funding.

We have seen a good horizontal integration of effort by phases; e.g. one lab designs, one assembles, and third tests. Integration of effort on individual phases, while stated to be planned, was not evident at this time. The program will benefit greatly if this was improved.

There has been progress in focusing efforts on fewer options before proceeding with hardware tests, but in the opinion of the LAPAC more

effort is needed to reduce options and thereby focus the application of limited resources.

- "Evaluate the balance between dipole and quadrupole R&D, and between technology development and focused model magnet development."

We have been told that of the five configurations "Quad 1st" was the primary approach and the "Dipole 1st" as the secondary approach. We concur with this, since the "Dipole 1st is a very technologically challenging and requires a great deal of innovation.

The May-03 proposal shows the dipole effort ramping up from $203K in FY05 to $2,501K in FY06, and all three magnet programs step down in FY07 by 10 to 20%. A large fraction of the dipole increase is for tooling. We question if it is wise to ramp up the dipole program that early at the cost of starving the quad program, which does not peak until FY08. This will further be stressed by the tax for the collimation R&D.

On the split for magnet development; we see in FY05 a $400k shift from quads to development; the effect of this is almost doubling the development budget, but cutting the quad budget by a factor of 5; lowering it to below the dipole budget. The reason for this shift was not discussed at the meeting. If this funding is returned in FY06, this may be reasonable; if not we question the focus of the program.

Balance between Dipole and Quadrupole efforts

Given the limited resources the magnet program must be well focused on the most demanding challenge given the present knowledge of the luminosity upgrade layouts. The LAPAC suggests that the main issue is the demonstration that the quadrupoles can be made in both short and long lengths. The committee emphasizes its believe that the demonstration of a working long quadrupole, the first of its kind in the world, will be a key element in the decision to formally start the design of the LHC luminosity upgrade based on Nb_3Sn.

Consequently the LAPAC recommends that allocation of US-LARP resources and scheduling reflect this priority. The program must be to go from short quadrupole models as fast as possible to the first long quadrupole magnet and to reduce the parallel tracks to a minimum.

Commentary on Technical Aspects of Magnet R&D

Dipoles

Currently the work is focused on the “dipole first” scenario, which must meet the most severe requirements: an open mid plane design with a very large magnet structure of about 15T and 10m length. The construction of such a “monster” magnet is far from trivial. The resources required to merely construct a relevant model are definitely not available within the current US-LARP program. Furthermore, the “dipole first” layout is considered the least likely one. Adoption of this layout would imply a threat to the success of the S-LHC since the basis for sound construction within a reasonable time is missing.

Since the new IR layout for the SLHC is presently not known, the LAPAC recommends that US-LARP magnet R&D effort on the “dipole first” be curtailed or reduced to a minimum. More specifically, the LAPAC recommends against going further than to deliver a low cost and simple demonstration model of such a block type magnet with open mid plane, preferably by using existing coils. This satisfies the demand for diversity in the R&D, and perhaps provides some insight into the challenges of the option for the first dipole layout. In any case it is important to maximize the resources for the quadrupole development that, for reasons stated above, should have the highest priority.

For the “dipole last” layout, the required dipole is most likely a 15T class wide bore cos(θ) magnet of moderate size. The development a very similar magnet, though not precisely the same, is already in progress elsewhere; with the present resources it is not justified for US-LARP to enter in this development.

Conductor

All magnet layouts presented are essentially based on OST strand material, which is at present the wire most readily available in the US. The relatively thick filaments of this wire demands the reduction of the strand size to the 0.6-0.8mm range. Consequently, this leads to the use of relatively small cables in 4 layer designs.

It is understood that the program budget limitations do not allow development of conductor with thinner filaments. The LAPAC recommends that progress in magnet construction techniques should not be slowed down because of non-optimal conductors.
However, magnet designers and those assessing the designs for practical application have to be aware of the bias that may lead to non optimal designs in terms of overall magnet cost.

Quadrupole Magnet R&D

The quadrupole magnet R&D program is the main priority of the LARP magnet program. The committee strongly endorses this choice as being the most appropriate vehicle to foster Nb_3Sn magnet development both in view of LHC luminosity upgrade and for internal US R&D needs.

The plan for the next three years calls for some subscale R&D work at LBNL, followed by construction of two to four short model magnets and some effort towards a long prototype.

The committee agrees that the subscale R&D is a worthwhile means to investigate some design and engineering issues in a cheap and fast turnaround manner. The subscale program should be tailored to the needs of the model magnet program and should focus on the problems of interest to it such as: flux jump instabilities, maximum allowable stress on impregnated conductors, maximum temperature after a quench and heat conduction through impregnated coils.

The committee was not presented with a back-up plan in the case the subscale-quadrupole exhibited flux-jump instability. What could be done to address this problem in a timely fashion with respect to the model magnet program?

The committee was pleased to see there was some effort to integrate the work of the design teams at Fermilab and LBNL. LAPAC feels very strongly that these efforts should be pursued and that designers at both laboratories should be involved in the follow up of the manufacturing. We recommend that LARP create a formal Working Group on magnet design and manufacturing, meeting at regular intervals.

Similarly, Fermilab and LBNL have now developed parallel experiences on the manufacturing of Nb_3Sn coils and it might be worthwhile to compare and reconcile these experiences, so as to come up with common procedures at the two laboratories for the subscale and model magnet programs. This reconciliation could be one of the tasks of the Working Group.

The committee was pleased to see that the LARP magnet team plans to keep close contacts with the NED program. It recommends to maintain and develop these contacts, and, whenever possible, to coordinate activities so as to ensure complementarities

The presentation of magnet development plan presented to the committee was difficult to read. It would help to have a Gant chart and/or a decision tree showing clearly the goals and the deliverables of this program.

The committee believes the short magnet development program as it presently stands is too diverse and too ambitious, in particular in terms of schedule. From that viewpoint, the committee feels it is unrealistic to expect that there will be enough time in the course of the next three years for the subscale program to feed back into the model magnet program, and for the results of the first "generation" model magnets to feed back into the second "generation" model magnet. As a result, these efforts may end up running in parallel, thereby loosing their coherence.

To enforce coherence it may be worthwhile to pursue all design computations to a similar level of maturity, and then, to select a baseline design and to stick to it for the short model and long prototype magnet fabrication. The 90 mm aperture seems a "conservative" and reasonable aperture to begin with.

The committee concurs that it is beneficial to build identical short model magnets, rather than to investigate variants. In the end, too much variety will make it difficult to compare results between the models to draw any useful conclusions.

The committee questions the value of building a magnet model that does not, from the very beginning, incorporate a coil alignment feature.

The committee stresses that it is important that the model magnets be adequately instrumented and cold tested to allow diagnostic of potential problems.

The committee was very pleased to see that the magnet program has put an increased emphasis on the length issue. The committee reasserts the importance of producing long prototypes. The feasibility of long Nb_3Sn magnets is probably the biggest unknown of this technology and has yet to be proven. The committee also understands that the manufacture of long magnets will require some significant investment in tooling, which must fit within the funding profile. LAPAC nevertheless recommends that everything be done to speed up these investments and to place a high priority on this part of the program.

The committee feels that some of the length- related issues might be addressed through an LMC program similar to the SMC program at LBNL and recommends that some effort be devoted to determining how and if this could be useful and cost effective.

Similar to the comments made above regarding subscale and model magnet, it was not clear from what was presented to the committee, how

the model magnet program fed back into the long prototype magnet and if there was enough time for it to do so.

LAPAC suggests that the following questions be considered:

- What are the requirements on field quality? Are they compatible with present conductor performance (effective filament size and its reproducibility)?

- What are the specification regarding radiation damage? It seems that the combination of high stresses and high radiation dose can quickly degrade impregnated coils. What kind of life-time can we expect from such a magnet?