LHC/ATLAS Upgrade Review

KEK, Nov 22-23, 2013

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Introduction

KEK commissioned a committee to review the proposed 10–year program of Japanese engagement in the planned upgrades of the Large Hadron Collider (LHC) and the ATLAS experiment. The program was conceived by physicists from KEK and Japanese universities under the leadership of T Kobayashi (Tokyo) and K Tokushuku (KEK). The proposed program comprised of significant contributions to the high-luminosity upgrade of the LHC accelerator (HL-LHC) and to associated upgrades to the ATLAS experiment.

The committee met at KEK on November 22-23, 2013. The proposal was laid out in individual presentations by the proponents in which they described their particular activity and proposed contribution. The committee then met in camera and composed an initial set of observations, which were shared with the proponents.

In preparing for the review the committee had also been presented with a set of criteria to guide the evaluation:

- Overall strategy of the proposal as an element of the Japanese contribution to the upgrade of the LHC;
- Coherence of the proposal with the ATLAS physics program and the overall upgrade plans
- General organization on the upgrade work;
- Soundness of the requested budget;

- Progress on the detector R&D;
- Relevance of the plan for the ATLAS/LHC collaboration;
- Relevance of the Japanese contribution to LHC operation and physics program.

Rather than meticulously following this structure the committee chose to address the criteria in the individual statements on the aspects of the proposed program, which follow after an initial assessment of the overall program.

Context of Review

The Japanese ATLAS/LHC groups have made outstanding contributions to the accelerator and experiments in key areas, including provision of LHC inner triplet quadrupoles and the design and construction of ATLAS's superconducting central solenoid magnet. In addition the groups have contributed significantly to the construction and operation of the forward muon-trigger chambers and to the silicon tracker. The LHC-Grid computing environment (Tier-2) installed at the University of Tokyo has regularly achieved high performance figures and has proved to be very reliable. The latter activity, however, does not fall into the purview of this committee.

Overall the committee arrives at the following observations:

- The Japanese groups have been very effective in design, construction and operation of their contributions. Their work has been essential to the success of the LHC and has been delivered in a very efficient manner.
- The groups are strongly engaged in the analysis of ATLAS data and have made essential contributions to the physics program including the discovery of the Higgs particle.
- The program has attracted young physicists who are now engaged in leadership roles.
- The program has also highlighted effective technology transfer and the capabilities of Japanese industry to address technical challenges and to deliver reliable components in time.

- The new program represents a wonderful opportunity for a successful continuation and international recognition of this excellence.

As a whole the committee is very much impressed by the proposed plan.

LHC Accelerator

The KEK group has proposed to build the superconducting single-aperture separation dipoles (D1) for the LHC. The currently installed separation dipoles have to be replaced with wider aperture magnets because of the planned insertion region optics changes which involves the installation of new inner triplet quadrupoles and a significant reduction of the beam size at the interaction point. This upgrade of the machine optics is key to the luminosity upgrade of the LHC. The Japanese engagement in the final focus project follows naturally from their contribution to the existing triplet system that was built in collaboration with Fermilab and CERN. It also leverages the expertise of the KEK magnet group and maintains the close collaboration with the partners at CERN. In Japan it calls for a strong engagement of Japanese hi-tech industry.

Several other, smaller activities on the accelerator support the breadth of the Japanese engagement at CERN. Such activities are seen to be relevant in radio frequency, in diagnostics and in explaining and overcoming beam related performance limitations.

As will be explained it may require that the proposed program be re-enforced with additional highly qualified staff in order to meet the stated goals. It should be added and emphasized that even modest contributions beyond the explicitly proposed components would allow for additional Japanese industry engagement in HEP as successfully realized in the past.

Accelerator – D1 Dipoles

The committee was presented with a well thought-out proposal for R&D, design and construction of the D1 dipole magnets. These magnets are key to the LHC upgrade. A delay in completion of these components would seriously compromise the start of the upgrade physics program.

An excellent design is being developed in close contact with CERN. Here the team is leveraging extensive past experience in superconducting magnet design and construction.

There is an impressively thorough analysis and detailed consideration of all key issues in preparation for a conceptual design report. The organization is good and the deliverables and timelines are well defined and will be fine-tuned as the project progresses. The plan up to model development requires more R&D. It is important that this phase receives the necessary resources.

The deliverables include two spare magnets besides the four magnets required for LHC operation including the one for the string test. This is considered prudent in view of the complexity and the importance of the magnets.

A proposed magnet test facility includes a horizontal cryogenic test bench. This would be a large investment and would stretch available manpower and technical infrastructure. The available cooling capacity at KEK is limited. Domestic safety requirements may restrict elements of the cryogenic testing of the completed D1 magnets and adversely impact the delivery schedule.

The proposed budget is probably realistic but without contingency. It runs at the level of 2-2.5% of the CORE value of the HL-LHC upgrade, which is somewhat smaller than the 4% contribution to the LHC as a whole in earlier times. This reduction can be attributed to the reduction in staff and the aforementioned lack of industrial engagement in hi-tech components beyond the dipoles.

The committee is concerned about the small number of experts and the continuity of leadership for a project of this size and of this duration. In fact, much of the overall expertise hinges on a single person, which evidently presents a risk. Even when considering the competence and the successful history of the group, more experts are needed to maintain close contact with domestic industry and CERN simultaneously. Additional staff is critical for the transition from the sound design to detailed engineering and fabrication. The shortage of manpower in this critical field has even wider implications: the number of experts world-wide is small. Thus it is important to try and recruit new staff and develop the required level of expertise.

While the proposed contribution to HL-LHC helps to maintain expertise at KEK in the domain of hadron collider science and technology the committee notices a certain lack of technological innovation. As an example, the Nb_3Al material studies had to be abandoned. It is hoped that with the proposed injection of additional personnel there may be room again to pursue innovative activities.

Given the importance of the D1 project the recommendations are further detailed below:

- Discuss with CERN the possibility of either: performing the cryogenic tests of the D1 magnets at CERN; or have CERN contribute the horizontal cryostats for use at KEK;
- Reassess the manpower needs taking fully into account the other responsibilities of the magnet group;
- Prepare a preliminary Resource Loaded Schedule in order to assess the ability of the organization to produce the proposed deliverables within the proposed budget.

Accelerator - Other projects

The program presents other welcome additions to the LHC accelerator program. These activities run at comparatively modest cost and comprise both hardware and intellectual contributions. The contribution to the LHC injector upgrade, which aims to produce beams with challenging levels of brightness, includes:

- The upgrade of the PS-Booster RF systems (ongoing) with a well-developed plan for staged deployment and testing of the wide-band FineMet-FT3L cavities and solid-state amplifiers is in place;
- The provision of 44 solid-state amplifiers that are required to power the RF cavities of 2 rings of the PS-Booster;
- Study, design and prototype of a longitudinal damper cavity system for the PS.

These contributions exploit existing facilities and established expertise in the novel application of new technology. The use and testing of the FineMet-FT3L technology at J-PARC will lead to its application at J-PARC.

The highly advanced superconducting RF infrastructure is available for cavity preparation and performance recovery demonstrated with KEKB-operated cavities. The crab-cavity technology was pioneered at KEKB and is one solution to overcome the luminosity reduction induced by the large crossing-angle necessary for rapid bunch separation either side of the interaction point. The LHC will profit from the available expertise and knowledge transfer.

In addition, the accelerator groups foresee to contribute their expertise in beam dynamics notably the calculation of electron cloud effects which present a possible limitation to the peak luminosity performance at the LHC and to advanced beam instrumentation based on synchrotron radiation emitted by the proton beams.

These contributions are significant contributions to the accelerator program, may become highly relevant for the operation of the accelerator and support the close collaboration with CERN.

In addressing specifically the involvement of industry it is noted that a broader participation of Japanese contenders introduces healthy competition and constitutes a great benefit for Japanese industry and technological development, an aspect that is also highly relevant in developments towards the ILC. It is recommended that some type of engagement, duly weighted against work accomplished in the laboratory, be maintained in the future.

ATLAS Detector

The Japanese research groups have chosen to engage in one experiment, ATLAS amongst the two general-purpose experiments at the LHC. This decision and the coherent approach of engaging in detector, trigger, operation and physics analyses with responsibilities for key components makes for a very strong visibility in ATLAS and beyond. In fact, the performance measured by any standard is canonically higher than expected from the resource share of Japan in ATLAS.

The proposed program is a natural continuation of their highly visible and successful contribution to ATLAS in key components of the experiment. Their proposed engagement is critical for the ATLAS upgrade and the success of the physics program.

The committee is very pleased to see that a new generation of bright physicists has emerged. They are introducing innovative ideas in detector construction, trigger and physics analyses and have already demonstrated leadership. The ATLAS groups should be commended for this achievement.

The proposed projects also offer the possibility to continue and expand the successful partnership with industry, which in several aspects is unique and world leading. It should be emphasized that the relevance of Japanese industry for particle physics detectors is worldsingular and reaches much further than supplying Japanese groups with high-quality detection devices. The more important it is that there be groups in Japan to maintain the direct dialogue to advance technology. ATLAS plays an important role in this context.

The committee observed that in order to guarantee fully successful and timely delivery of the complete program, more people would be beneficial. The actual date of delivery of upgrade components depends on the evolution of the overall LHC schedule, which leaves little room for delays in completion. Completion of the R&D is hence critical.

ATLAS Tracker Upgrade

The physics goal of the LHC upgrade is twofold: increase the (integrated) luminosity significantly and maintain or exceed the precision of the detectors that has been reached in operating situations with lower event pile-up. These two aspects allow for precision studies of the discovered Higgs particle and extend the direct searches for new physics to the highest mass scales.

Without a tracker upgrade the physics program is not viable. The current tracker will eventually suffer from radiation damage and does not provide the granularity that is commensurate with the occupancies expected at higher luminosities that will be provided by HL-LHC. The tracker is the key component that allows to separate interaction vertices and therefore helps unfolding pile-up contributions in the calorimeter.

In the construction of the tracker ATLAS fully relies on the expertise of the Japanese groups and industry. ATLAS expects to converge on a final design for the tracker by 2015. The detailed technology choices, i.e. sensors and assembly, will depend on the R&D program, in which the Japanese groups play an important role. The ongoing sensor R&D in Japan is critical.

The commitment in the tracker upgrade construction is hence a wise decision: the Japanese groups will be able to profit from their engagement in R&D, maintain a leading role and have the advantage of direct contacts to leading Japanese manufacturers.

The specific commitment of the Japanese groups will depend on the outcome of the R&D and ATLAS decision process. The overall size of the tracker upgrade program will certainly require the budget presented and little depends on sensor technology. The proposed contribution compares well with previous and present Japanese engagement in large international HEP projects.

Overall this is a high-profile and rewarding endeavor.

ATLAS Muon Detector

The ATLAS muon spectrometer consists of several components: precise muon momentum measurement is provided by monitored drift tube chambers (MDT) over most of the coverage, supplemented by cathode strip chambers (CSC), arranged in so-called „small wheels“ at small radii in the end-cap region. Resistive Plate Chambers (RPC) and thin-gap chambers (TGC) are used in the central and end-cap regions, respectively, to provide the muon trigger. The goal of the muon detector upgrade is to provide better muon momentum selectivity at the trigger level and robust muon measurements in the difficult forward region by replacing the small wheels with new detectors.

The New muon Small Wheel detector (NSW) will consist of TGCs and Micromegas. The TGC is based on the existing chambers albeit with finer readout strips for good position resolution and the addition of cathode pad readout for on-line track finding. It will serve to precisely reconstruct track segments at the primary trigger level, while the Micromegas will be used for precision momentum measurements during full event reconstruction. The proposal for the New Small Wheel muon detector has been presented as a Technical Design Report, which has been critically reviewed. The Japanese groups have decisively contributed to the physics case of the NSW detector. They plan to engage strongly in the R&D of the Micromegas both at Kobe and Tokyo University.

The committee was convinced that the Japanese groups have the competence to deliver a working detector for phase 1. Possible upgrades for phase 2 still have to be investigated.

ATLAS Muon Trigger

The trigger is essential in extracting the physics at the LHC and the physics to be gained from the upgrade in particular. The higher the pile-up and the occupancy is the more relevant the sophistication of the trigger and the importance of lepton signatures becomes, particularly in the forward direction.

The Japanese groups in ATLAS contributed significantly to the construction and operation of the thin-gap chambers and had full responsibility of the delivery and operation of the forward level 1 trigger of the TGC. This project naturally continues their detector engagement.

The proposed engagement follows the operating demands of the LHC. Initially the TGC information from the present small wheels will be made available for coincidence logics and subsequently, with the advent of the New muon Small Wheel detector, be extended to the reconstruction of muons pointing to the interaction point. The NSW will have standalone tracking capability and hence provide much more selectivity.

The Japanese groups will provide the sector-logic firmware and some hardware components. The proposed solution is technically sound, fulfills the requirements and naturally extends into an engagement on the future upgrade for phase 2-running after long-shutdown 3. ATLAS relies on their unique expertise for the successful upgrade of this vital component.

New Engagements in ATLAS

New university groups joined the Japanese ATLAS group and to some extent bring new ideas for relevant engagement in ATLAS. Such engagement is partially driven by experience of the principal investigators gained during affiliation at institutions abroad. Such new areas of involvement add to the breadth of the physics program at relatively modest cost with potentially large benefits in physics and technology.

The two projects of this kind are

- Liquid argon (LAr) calorimeter trigger and electronics
- Fast Tracker Trigger (FTK) for phase 1

The LAr calorimeter trigger upgrade improves the granularity of the calorimeter at the first trigger level so as to improve the rejection of background when operating at larger than design luminosities. The existing readout will be augmented, and later replaced, by a parallel digital readout of the same information in finer resolution which allows for better identification of calorimeter objects and further topological processing in the central trigger processor.

For that matter the Japanese groups will concentrate on the backend signal transmission using mezzanine cards placed on electronics boards according to ATCA standard. They will also contribute to the front-end reconstruction of energy signals using FPGAs.

The Fast Tracker Trigger (FTK) employs massive use of associative memory to enable track reconstruction and momentum measurement in real time. The engagement results from a prior engagement of the Waseda principal investigator with the initiator of the original proposal, the University of Chicago. The activity in Japan focusses on the development of the mezzanine board for massive exchange of track information over the backplane and continues with studies of future applications of the track trigger concept at LHC phase 2.

Both proposals have in common the exposure to advanced electronics implementation at the interface of physics algorithms and firmware implementation. Such skills are in high demand and clearly beneficial for the field and beyond. The cost of either of these programs is modest in comparison to the larger upgrade items. At the same time they attract a relatively large number of students.

Both programs nicely complement the physics diversity of the Japanese LHC engagement.

Conclusion

The proposed 10-year engagement of the Japanese HEP community at the LHC and the ATLAS experiment rests on two main pillars: the construction of the superconducting beam-separating dipoles and significant contributions to the new tracker of the ATLAS experiment. Both activities entail significant involvement of Japanese industry and bind the majority of resources. These flagship activities are complemented by a number of smaller activities for the accelerator and detectors, and attractive engagements often driven by universities, where young researchers enter the field and are seen to take the lead.

The LHC/ATLAS team has built a reputation of successful construction of accelerator components and HEP-detectors. As one of the leaders in the field they will contribute significantly to the upgraded LHC, the high-energy frontier project of the field.

The budget presented has only been resolved at the top level. The D1-dipole will be constructed in industry; since the design has not been fully completed the cost of the magnets, including the tests is uncertain. Given this boundary condition it is mandatory that sufficient expert staff be found and assigned to the project to avoid surprises during construction. – For the phase 2 tracker upgrade the technology choices have not been made to arrive at a more detailed budget assessment, although there is little doubt that the order of magnitude of the cost is correct. The committee is confident that given the large international framework in which the tracker R&D and construction is placed, the right technological choices for the tracker will be made. Japan fulfills a particularly important role for the tracker upgrade with the relevant hi-tech industry in the country.

Beyond the two flagship activities the committee saw a rich and diverse activity in Japan in the detector, trigger and physics analysis and – to a lesser extent – in the accelerator field. The Japanese contributions to the LHC and the ATLAS detector are vital and reach beyond the financial contributions. In view of this high standing the committee strongly supports the efforts of the ATLAS/LHC Japanese teams to ensure that competence and leadership are effectively transferred from senior scientists presently in charge of the various activities and projects to the younger generations.

The Japanese groups have been particularly talented in generating high impact at the LHC both in terms of performance of the accelerator and in physics return. Japanese industry in many respects is world-leading.

Overall the committee is very pleased with the proposed plan, which is sound and guarantees high visibility at the LHC and in particle physics in general.