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Closeout Report

Director's CD-2/3 Review of the HL-LHC ATLAS-US Project

June 27-30, 2022

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1.0 Executive Summary

A BNL Director's Review of the HL-LHC US-ATLAS project was held remotely from June 27-30, 2022 to assess the project's readiness for a DOE CD-2/3 IPR scheduled for October, 2022. The review committee examined the design maturity of the various elements of the project, the status of R&D and prototyping studies, the proposed baseline cost and schedule along with the basis of estimates, the risk planning and analysis, the integration, interface, and procurement planning, and ESH processes. The committee's findings, comments, and recommendations are provided below in "Trigger and DAQ", "Liquid Argon Calorimeter", "Global Mechanics", "Silicon Strips", "Silicon Pixels", "Cost and Schedule", and "Management" areas. Also included are the committee's replies to the charge questions. The charge for this review and the review committee membership are included in the Appendices.

The review was conducted over a 3.5 day period and began with a full day of plenary talks that provided an overview of the project and each L2 system and summarized the proposed baseline cost and schedule including contingencies. The following two days consisted of parallel breakout sessions that provided additional details for each L2 system, allowed for cost and schedule drill downs to occur on selected control accounts, and included short plenary sessions for the project to respond to committee questions from the previous day. The last half day was dedicated to report writing, a dry run, and the plenary closeout session.

Good technical progress has been made across the entire project over the last year. It appears that technical readiness level 6 or better has been achieved across the project. ATLAS-led Preliminary and Final Design Reviews have occurred for many of the components and the required performance has been demonstrated in many instances with prototype articles. A Final Design Report for the project has been produced and is under independent review at the time of this writing. The feedback from the independent review is scheduled to be received ahead of the DOE IPR in October. In general the committee believes the technical maturity of the L2 systems is appropriate for this stage of the project and supports CD-3. For those elements not yet ready to begin fabrication, the project has a clear plan and mature processes in place to ensure the designs, interfaces, etc achieve the appropriate level of maturity prior to initiating construction of production components.

Something about RLS and risk…

Something about area of improvement that were identified…

…

In summary, the committee has identified no significant concerns or show-stoppers. While improvements are needed in some areas, the committee believes that the HL-LHC US-ATLAS project has sufficient time and resources to address these in a timely manner and is well positioned to succeed at the DOE IPR scheduled for October.

2.0 TDAQ

Subcommittee: Ed O'Brien* (BNL), Paul Rubinov (FNAL)

Answers to Charge Questions

1.Does the proposed technical design satisfy the performance requirements? Do the key performance parameters provide a satisfactory indication of the project's completeness?

Yes.

3.Have the project's risks been fully analyzed and accounted for in the contingency estimate?

Yes, see comments.

4.Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

Yes.

9.Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

Yes.

1a. Have the final designs been appropriately reviewed by the project and are the designs ready to support fabrication? Was an independent final design review conducted?

Not yet. However, the TDAQ deliverables contain no critical technical elements and all challenging technology issues have been demonstrated to work in prototype boards. The

TDAQ L3 elements have passed their SPRs and there is a well-defined plan and mature processes for completing the required Intl ATLAS FDRs ahead of major expenditures.

2a. Is the planning for major procurements, interfaces between subsystems, and integration of the project adequate to proceed with fabrication?

Yes.

Findings

- The USATLAS TDAQ upgrade has three L3 WBS elements in its DOE scope:
    - Global Trigger hardware and multiplex firmware
    - FELIX hardware and firmware
    - Readout interface firmware
- The DOE TDAQ scope is met by these deliverables:
    - Design and production of the Global Common Modules (GCM) and its associated firmware. 18/54 production boards to be delivered
    - Design and production of FELIX cards (phase-2) and its associated firmware. 200/584 production boards to be delivered.
    - Readout interface firmware to support GCM to FELIX data transmission. Event Filter firmware for data transmission and data prep for tracking algorithms.
- The GCM and FELIX efforts have passed their Specification Reviews. The FELIX passed its PDR in Jan 2022 and has a scheduled FDR in July 2023. The GCM PDR is scheduled for May 2023 and its FDR for May 2024.
- The key hardware for the project exists is the form of prototypes (GCM prototype v2b for 6.7.1 and v1 FELIX using the Xilinx VM1802)
- Due to the reliance of the project on commercial, off-the-shelf (COTS) based hardware, the strategy for this WBS is to demonstrate key technical areas but to delay major production and purchasing until the last possible moment to take advantage of the latest commercial developments. As a consequence, the FDR (Final Design Review) for those parts of the WBS 6.7 that involve hardware (6.7.1 and 6.7.3) are scheduled as late as possible (May 2024 and July 2023 respectively). For 6.7.4.1 where the deliverable is purely firmware, the project is complete at the time of the PDR. This strategy is fully captured in the project plan.

- WBS 6.7 meets TRL 7 because commercial components that meet the requirements exist and the components will be operated only in an equivalent environment (i.e. not cold, not exposed to radiation)

- The Event Filter(EF) development was updated by a BCP in April 2022. This was driven by a technology downselect by ATLAS, which chose commodity-based Event Filter Tracking over a Hardware Tracking Trigger as the technology for a high-level trigger.

    - The EF L3 is seen as a scope opportunity (ie. contingency spend down) with a PDR needing to be reached prior to a technology selection by Intl ATLAS. This should be added to the scope contingency document prior to the DOE CD-2/3 review.

    - The project team has played a critical role in a recent (approved by LHCC/UCG and RRB in spring 2022) technical choice made by the ATLAS collaboration to use commodity-based option for Event Filter Tracking. This is captured for the project in BCP-070.

- There are no Critical Technology Elements in the USATLAS TDAQ HL upgrade. All deliverables use custom off the shelf components and protocols. Key technologies have been demonstrated on prototypes based on ATCA (GCM) and PCIe (FELIX) hardware.

- Detailed Basis of Estimate documents, RLS, Risk Registry, a Cost Book, procurement plan as well as detailed prototyping and development plans all exist for the TDAQ upgrade.

- The major material purchases will be carried out through CERN and the commitment of the project is defined by the ATLAS MOU.

- There are KPP's defined for the TDAQ deliverables.

- The GCM and FELIX board production will be handled by CERN.

- There was one recommendation for the TDAQ subproject from each of the past two independent reviews. The recommendations were addressed and closed.

Comments

- The TDAQ deliverables are well defined.

- The Procurement Plan is detailed and reasonable.
- Reasonable TDAQ interface and integration plans exist.
- Both the GCM and FELIX are at an advanced hardware prototyping stage with technical risks having been retired and the need for future firmware development well defined.
- The project has made very impressive progress, especially in the key technical areas of very high speed serial links (>25gbps), compliance with ATCA standard and PCIe gen 4 interface.
- There is a very strong and experienced technical team working on the TDAQ deliverables for US ATLAS. They have an excellent track record of success from past projects, and have made good progress to date on HL upgrade tasks despite the challenges from numerous external factors.
- Significant effort has gone into TDAQ group member succession planning, which should have a positive impact on group effectiveness as work evolves from prototyping to production, through commissioning and to operation.
- All TDAQ Cost, Schedule and technical documentation provided were at a level of detail consistent with expectations for a CD-2/3 review.
- The TDAQ elements in the Risk Registry are reasonable and sufficiently detailed for a project asking for CD-2/3 approval.
- The technical plans described to bring the TDAQ deliverable development from its present state to one that meets the KPPs were detailed, comprehensive and credible.
- The TDAQ cost and schedule is credible.
- The TDAQ KPPs can be met based on the technical, cost and schedule plans presented.

Recommendations

- None

3.0 LAr

Subcommittee: Ted Liu* (FNAL), Paul O'Connor (BNL)

Answers to Charge Questions

1.Does the proposed technical design satisfy the performance requirements? Do the key performance parameters provide a satisfactory indication of the project's completeness?

Yes, the technical design of the Preamp/Shaper ASIC and the integration test stands will satisfy the performance requirements.

3.Have the project's risks been fully analyzed and accounted for in the contingency estimate?

Yes.

4.Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

Yes, most of the team are ATLAS LAr veterans and long-time collaborators with international partners.

9.Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

Yes. In response to the IPR Director's Review in December 2021 the presentations at this review included a thorough overview of the NSF side of the LAr development. There were no recommendations from the January 2022 DOE/SC IPR.

1a. Have the final designs been appropriately reviewed by the project and are the designs ready to support fabrication? Was an independent final design review conducted?

Almost - The ALFE2 ASIC is a Critical Technology Element whose Final Design Review is scheduled for Fall 2022, but the subcommittee was shown comprehensive test data from the final prototype showing that the design is in compliance with all requirements.

2a. Is the planning for major procurements, interfaces between subsystems, and integration of the project adequate to proceed with fabrication?

Yes.

Findings

1. 6.4.5 Preamp/shaper

BNL will produce a 4-channel CMOS ASIC Preamp/Shaper (PA/SH). The current prototype is well characterized and meets performance specifications, including radiation. Production quantities will be tested robotically using a custom test stand at BNL. Chip fabrication and testing will be cost-shared 50/50% with i-ATLAS collaborators at IJCLab and Omega. The PA/SH FDR is scheduled for October 2022, PRR in June 2023, and completion of all production QA/QC testing in April 2025. The critical path runs through the ALFE FDR.

2. 6.4.4 FEB System Integration and Production Testing

BNL is responsible for the three Level-4 WBS elements: construction and operation of a FEB2 analog test stand, construction and operation of a test stand to verify the LAr back-end electronics, and development of a QA/QC database to track production of the US deliverables. This WBS has several external dependencies: 20 prototype FEB2s are to be provided by Columbia (NSF ATLAS) in the first quarter of CY2024, followed by production quantities in early 2025. For the FEB2 test stand, a number of supporting electronics boards for the FEB2 and system integration tests are to be supplied by non-DOE US and international ATLAS collaborators.

Comments

Overall comments:

The progress on this project made so far has been very impressive, in particular, the recent excellent results from testing the ALFE2 ASIC (including TID and SEE) are to be commended. We note that the system being developed for Phase 2 is much more challenging than the Phase 1 system as the data throughput between the frontend to the backend is increased by a factor of 200. The team is highly experienced and has worked together successfully for many years delivering key components for the original detector and for the Phase 1 Upgrade.

A full-scale (128-channel) FEB2 prototype design is well-advanced at Columbia (NSF). It will serve both to validate the 6.4.5 Preamp/Shaper performance in a near-final electronic environment, and as a test article for the FEB2 test stand development in 6.4.4.

6.4.5 Preamp/shaper

The preamp/shaper design (ALFE2) has made great progress. Based on results of the recent test campaigns, the ALFE2 ASIC has been shown to satisfy all of its performance requirements including radiation hardness.

There are still two technical issues to be resolved, one is related to the packaging option and the other is related to the choice of I2C interface approach. To fully qualify the design, the ALFE2 ASIC needs to be tested with ADC chips on a full size front-end board (FEB2). The team is quite confident that there is no need to modify the ALFE2 design regardless of which option is chosen, as the changes can be made to the rest of the system. It is important that the (international) ATLAS LAr agrees with this. The packaging change to BGA is not expected to influence the performance characteristics. The project has

retained a risk (6-04-05-004, risk impact rank 140) addressing the possibility that an additional iteration of the PA/SH ASIC will be required. We strongly encourage the project to re-evaluate this risk before the CD2/3 review.

The CERN FDR of the ALFE2 PA/SH as well as full size FEB2 testing will not occur prior to the DOE CD2/3 review. Therefore, we strongly encourage the project to compile a comprehensive report detailing the performance, functionality, and radiation tolerance of the ALFE2, to support the case that the current prototype design has been thoroughly vetted and is ready for pre-production.

6.4.4 FEB System Integration and Production Testing

The US scope is to fully test and qualify 806 FEB2 boards and to perform the full chain vertical slice system integration of the FEB2 boards, the phase 1 trigger boards, a calibration board, the backend electronics and the TDAQ. The production testing for the FEB2 boards is planned to be done at BNL, and the vertical slice system testing is now planned to be done at CERN instead of at BNL as was planned before. The first tests of the final FEB2 board are scheduled for after CD-2/3 review, so only results obtained with the 32-channel slice test will be available for the review.

The data throughput between FEB and LASP is two-hundred times greater than the existing system. This data throughput is a challenge in itself, and could likely reveal problems before and during production. The system integration of the FEB2 and the off-detector electronics is complicated by dependencies on several components that are outside of the DOE scope. Some are from French collaborators and some are from the NSF side of the project. Any delay in this pipeline could delay the completion of 6.4 with concomitant cost increments. The project is using board emulator to mitigate some of the risks associated with possible board delays and allow early tests and this is a good approach.

Comments on presentation:

The estimated effort (labor hours) for ALFE and FEB2 testing appears adequate, but in future reviews it may be helpful to present the testing rates in units/hour, for example. The schedule graphics in the subsystem breakout presentation had only coarse granularity, did not break out tasks by L4 elements, and did not include milestones or show the critical path.

Recommendations

None

4.0 Global Mechanics

Subcommittee: Mar Capeans (CERN), Walter Sondheim* (LANL)

Answers to Charge Questions

1.Does the proposed technical design satisfy the performance requirements? Do the key performance parameters provide a satisfactory indication of the project's completeness?

YES.

3.Have the project's risks been fully analyzed and accounted for in the contingency estimate?

YES.

4.Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

YES, FY 2022 and 2023 will be key to final production of key items as part of this project.

9.Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

YES.

1a. Have the final designs been appropriately reviewed by the project and are the designs ready to support fabrication? Was an independent final design review conducted?

YES, the GM group is well into long lead time fabrication as a part of CD-3A approval.

2a. Is the planning for major procurements, interfaces between subsystems, and integration of the project adequate to proceed with fabrication?

YES, closely working with both the pixel and strip subsystems has been ongoing and services have been integrated into CAD models - which was previously mentioned in earlier reviews

since space is limited for all the required services. Full scale mock-ups have been constructed which have been critical to understand service routing.

Findings

- Strong and experienced team, in particular on large C-fiber structures for HEP experiments. This is well reflected by the progress, being ahead of other subsystems, and the compliant technical quality delivered to date. Prototypes and a significant part of the final components have already been successfully procured and qualified. The chosen strategy to design, procure, accept and assemble these large GM items using external vendors and in-house has proven successful.
- The level of maturity handling interfaces (under 6.3.1) is in good shape, despite some basic specifications for services still subject to change like the connectivity plan for strips or some possible changes in the services, like an increase in diameter of cooling flex-pipes. The potential impact can be technically accommodated. Ongoing work on the 1:1 services mockup at CERN has helped to identify particular services routing and try out ad-hoc solutions. This practical knowledge will be documented in the form of guidelines/procedures. Interfaces are approved at ATLAS level at the FDR stage, and lastly, one for GM (IST/IPT) is planned in Oct 2022. Special attention is still to be paid to unexpected additional weight.
- Annual Integration workshop is the forum in ATLAS where interfaces are discussed and reviewed, integrating other 'external' systems like DCS, DSS, DAQ. Frequency of these meetings will increase to twice or more per year to coordinate better the information across systems and prepare for overall integration.
- Still on services, as the work progresses to outer radius, new interfaces with other subsystems (calorimeter, muon system, liquid Argon) have to be controlled implying interactions with communities which are less familiar to the Tracker team. Configuration management and conflict management at ATLAS level becomes crucial.
- Bulkheads are on a path to be completed.
- A complete grounding and shielding plan has been developed by a team at UC Santa Cruz, all proposed connections for the GM deliverables for this have been tested.
- Transportation risks seem under control, with several options being explored. Adequate shipping containers have been identified that do not limit this shipping strategy (plane, ship). A dedicated person for organizing and following the GM logistics has been appointed.
- Readiness: Previous recommendations have been addressed, Limited risk exposure, Nominal float: >12 m. Global mechanics is ready for CD-3.

Comments

IST has a comfortable production and assembly schedule, CD3 would give ok for material order in early 2023. The project team shall seek ATLAS approval to procure the base material before passing ATLAS Pixel FDR and PRR to happen later in 2023.

The team has acquired unique practical knowledge during the QC of C-structures, including successful repairs at the vendors and in house. This knowledge will have to be retained and transferred to CERN, to make sure that controlled repairs remain possible during the handling of structures at assembly sites and during the final phases at CERN. A stock of spare materials and tools should be kept available (at vendor premises) and at hand for repairs or replacements anywhere.

6.3.6 (infrastructure) has been completed with a new building commissioned at LBNL, despite delays due to COVID and general infrastructure accidental events. The reliability and operational stability of this unique facility should be a priority for the lab during the production phases.

Is there a risk to possible delivery delay for the pixel support tube based on CD3 funding being available - ATLAS management says no. Even with a continuing resolution, funds would be available for material purchase. There is a lot of float available for the fabrication of the pixel support tube at LBNL - to meet delivery in England for assembly.

E. Anderssen appears in the organization chart as a possible single point of failure, but it was clarified that two persons could take over if need be. Installation and Integration (I&I) plan and risks are understood by the team and will be further detailed as the project's proceeds and materials start arriving at CERN for assembly and testing. Paying attention to International ATLAS deliverables as a part of GM I&I at CERN should be tracked.

Recommendations

1) Prior to the DOE CD-2/3 review, revisit the I&I resources plan (FY25-28), in particular reviewing the amount of technicians needed at CERN, which as planned now seems too low, and the current traveling plan/resources during LS3 (FY26-29).

5.0 Strips

Subcommittee: Ron Lipton* (FNAL), Rachid Nouicer (BNL), Matt Rudolph (Syracuse)

Answers to Charge Questions

1.Does the proposed technical design satisfy the performance requirements? Do the key performance parameters provide a satisfactory indication of the project's completeness?

Answer:
Yes, the technical design meets the ATLAS requirements.
We have comments on "cold noise".

3.Have the project's risks been fully analyzed and accounted for in the contingency estimate?

Answer:
Yes.

4.Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

Answer:
Yes, but more commitment in labor from institutes and universities will be needed to reach full production .

9.Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

Answer:
Yes.

1a. Have the final designs been appropriately reviewed by the project and are the designs ready to support fabrication? Was an independent final design review conducted?

Answer:
Yes. All subsystems have passed ATLAS Final Design Reviews and are expected to undergo Production Readiness Reviews (PRR) before DOE CD-2/3 review.

2a. Is the planning for major procurements, interfaces between subsystems, and integration of the project adequate to proceed with fabrication?

Answer:
Yes.

Findings

- The ABC* chips tested in the initial batch of 200 wafers show low yield, due to bit flips in the SRAMs. The yield drops sharply when operating at voltages only slightly below the nominal . This is being investigated by the designers and the foundry. Yield can be recovered by operating at higher voltage (up to 1.4V).
- An anomalous noise issue was recently (May 11) found in testing short strip modules. This noise occurs when the temperature is below a (varying) threshold. It does not appear to be related to HV breakdown. It seems to affect a significant fraction of short strip modules. Investigations are in an early stage.
- The initial vendor for bus tapes (laminated as part of the stave structures) was acquired by another company and production was transferred to China. Preproduction tapes from that vendor have not met specifications. Samples from CERN do meet most specs and are now the default vendor for these parts.

Comments

The review committee commends the strip team for the obvious hard work and preparation that went into this review. The strip detector construction should move forward. The strip panel would like to point out following observations:

- The scope of the strip detector construction is well defined.
- Strip team has a very experienced scientific, technical, and management team in place. The team developed a high-quality integrated resource-loaded schedule, appropriately detailed cost estimates, and an adequate risk assessment to establish a baseline and cost estimate to successfully achieve the goals.

ABC* Yield - The group has done a good job addressing the yield issues in the ABC*. It has been isolated to an old SRAM design. The plan to solve the ABC* memory issues through increase of the operating voltage seems a sensible path forward, given that it can be easily accommodated in the cooling budget. This option has been tested by thermal and irradiation testing of sample chips. The possibility that process control improvements may also remove this need greatly mitigates the risk. The next ABC* wafer order will be placed in August. ATLAS has to decide on any change on the baseline operating voltage or wafer process by that time.

Cold Noise - The team has shown that they are making good progress towards understanding the cold noise problem observed in Short Strip modules, and we feel they have good prospects for solving it. The timescale for identifying a fix, implementing, and approving it is, unfortunately, extremely tight going towards the DOE - 2/3 review in fall. Short Strip sensor production is planned to begin in June 2023.

Personnel - Module and stave production requires a dedicated staff of trained technicians, engineers, scientists, students and post-docs. There is some danger of a shortfall. Six new technician hires are

still needed. New hires will require overhead of job requisitions, candidate search and on-boarding. This varies from institution to institution. The work involves specialized skills that will require significant training time. It is not clear that full staffing will be achieved for the start of production. In addition, the contributed labor will require adequate research funding for university groups. Recent funding trends are not positive, leading to possible shortfalls. This would have to be made up by additional technical staff hiring. This is included by the project as a risk.

Modules - Modules are on the critical path for the strips part of the upgrade. The module production rate is essentially saturated by the planned personnel and equipment at the three production sites with little margin for speed-up. This implies that any delay in fabrication start will reflect directly in the finish date of the project. Float currently appears adequate but this needs to be closely monitored as delays inevitably accumulate**.**

Stave - Concerns were raised in the event of failed silicon modules assembled on staves. It is not easy to remove them. In this case the project plans to utilize spare staves and avoid rework. A well-developed plan for stave repair could be useful as a backup solution in case of low stave yield.

Bus tapes - ATLAS is qualifying CERN as a vendor for the bus tapes after Altaflex was acquired. This appears to be going well, but it would be good to continue to pursue the Altaflex Chinese sub-contractor to have a possible second vendor for this unique component.

HCC* - The HCC* was successfully redesigned with triplicated logic to improve immunity to single event effects. The resulting chip has been thoroughly tested for functionality and radiation resistance. It is ready for a Production Readiness Review in July.

Recommendations

2) Prior to the DOE CD-2/3 review, develop a plan to address the cold-noise issue.

6.0 Pixels

Subcommittee: Karl Ecklund* (Rice), Gabriella Carini (BNL), Nicola Bacchetta (FNAL)

Answers to Charge Questions

1.Does the proposed technical design satisfy the performance requirements? Do the key performance parameters provide a satisfactory indication of the project's completeness?

Yes.

3.Have the project's risks been fully analyzed and accounted for in the contingency estimate?

Yes, with a comment.

4.Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

Yes, with some comments.

9.Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

Yes, with some still being completed.

1a. Have the final designs been appropriately reviewed by the project and are the designs ready to support fabrication? Was an independent final design review conducted?

Yes, see findings.

2a. Is the planning for major procurements, interfaces between subsystems, and integration of the project adequate to proceed with fabrication?

Yes.

Findings

- The ATLAS Final Design Review (FDR) for Modules, and Production Readiness Review (PRR) for the FE ASIC have been successfully held in May and June 2022.
- The ATLAS FDRs for local support and services are scheduled in September/October 2022 will be likely ahead of the DOE CD-2/3 review.
- ATLAS Production Readiness Reviews (PRR) prior to production tasks are on the US pixel schedule following pre-production, and the project is at an appropriate stage for CD-2/3 approval.

Comments

- We congratulate the team on the significant technical progress since the last Director's Review, which demonstrates their readiness to deliver the proposed technical scope.
- The project has successfully constructed RD53A prototype quad modules and delivered 23 for integration tests. The module yields are not yet demonstrated at the level required for production. While this may be expected, it is important to properly assess the yield with pre-production parts. Also, the module assembly sequence and tasks duration evaluated from RD53A prototyping should be updated from pre-production experience as that progresses.
- The committee notes that irradiation and SEU tests were performed for the FE ASIC, showing sufficient performance with mitigations on module and system design. These should be repeated for the final chip.
- Cooling & mechanics design and prototyping is nearly complete. L1 staves will shortly be completed. We suggest to also build the type 2 cooling tube prototypes. Results from initial thermo-fluidic tests are understood and will continue. Likewise, continue to pay close attention to the complex routing and assembly of the cooling and service interfaces.
- The carbon fiber quarter shells are made at the Composite Manufacturing & Simulation Center at Purdue University. We suggest to closely follow the schedule as the vendor is highly subscribed.
- There are some significant schedule risks for international deliverables. These are captured in the risk register. Given the likelihood of delays, we suggest :
    - a careful reevaluation of schedule and cost impacts for late arrival of parts from international partners
    - maintaining or increasing flexibility in downstream activities and further developing risk responses for module assembly and integration activities to provide margin to meet the ATLAS need-by date
    - considering the need for an agreement now for potential additional technical staff at the module assembly site (Argonne) to maintain or recover schedule. The present staff level appears to be just enough to maintain the nominal rate of production.
- We strongly encourage the project team to pay close attention to tracking and logistics for components across the project. Continue work to put in place tools (data base, traveler

documents, tracking shipping, etc) to follow the distributed project and practice using them during the remaining prototyping and pre-production activities.

- We suggest adding a risk for FE ASIC testing capacity that activates the backup site at LBNL for FE ASIC wafer probing.
- There is a large ramp-up in scientific labor during integration. Continue your effort to involve students, postdocs from other institutes to ensure adequate scientific effort can be available at SLAC for integration during production in FY24 and FY25.
- The committee noted that some presenters were frequently interrupted when attempting to answer questions. We suggest allowing presenters to answer fully or allow *them* to defer to others for details or clarifications, rather than speaking over them.
- Sharp and focused presentations that address the charge questions with notation, would help the committee and avoid some questions for clarification.
- The committee acknowledges that responses to prior recommendations are still in progress. Of four recommendations, one is closed and three remain open and are expected to be completed by the ATLAS FDR for local support and services prior to the CD-2/3 review.
- The float in the present pixel schedule to the ATLAS need-by date is insufficient. When including additional ATLAS-held contingency the schedule can be met. As presented, this may be a cause for concern at the DOE CD-2/3 Review. A crisp plan for how this shall be handled would be helpful in passing that review. We understand that such a plan involves more than the U.S. Project.

Recommendations

3) As risks are reevaluated in light of technical progress for the DOE CD-2/3 review, if there is still need to access the ATLAS-held contingency, discuss with ATLAS and other stakeholders to develop a plan to meet the overall schedule with high confidence level. Present this crisply at the DOE CD-2/3 Review.

7.0 Cost, Schedule and Project Controls

Subcommittee: Ruben Carcagno* (FNAL), Cherie Chance (ORNL), Lipika Swarup (FNAL)

Answers to Charge Questions

2.Is the resource-loaded schedule complete, consistent, and credible so that it can serve as the cost and schedule part of the project's performance baseline? Is it compatible with the funding guidance provided?

For the most part. See comments and recommendations for issues related to schedule.

3.Have the project's risks been fully analyzed and accounted for in the contingency estimate?

It would appear so, but given the issues with the schedule and contingency breakdown we were unable to verify. See comments for details.

4..Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

Yes.

6.Does the project have a certified EVM system and has the project demonstrated the ability to utilize it as an effective project management tool?

Yes.

7.Is the documentation required by DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, for CD-2 complete and in good order?

Yes for Cost and Schedule, but the RLS needs some work (see comments and recommendations).

9.Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

They have been addressed, but there is an open recommendation (see comment about open recommendation on project personnel agreements).

Findings

DOE guidance for the DOE scope is for a TPC of $195M. NSF MREFC funding is $75M. DOE funding profile guidance was available, and it was last updated in May 2022. It now includes provisions for COVID delays and cost impacts and support of Integration and Installation activities to the end of LS3.

Deliverables account for 88% of the TPC

CERN LS3 shutdown starts in Jan 2026 and has a duration of 3 years. ATLAS need-by dates for project deliverables are available and used to compute subsystem schedule contingency. There is float

between the completion of each subsystem and the CERN need-by date. The minimum float is 12 months.

CD-2/3 ESAAB approval anticipated in Q1 FY23, project moving into production in January 2023

CD-4 (Q1 FY 2031) includes two years of float

CD-3a approved 10/16/2019 for $12.9M. The contingency on work to go was 41.4% to start, now (42.4% complete) is down to 23.4%. The project believes that the remaining risks do not warrant additional contingency at this time.

There is a positive balance/carryover in each FY which helps ameliorate the effect of funding delays (Continuing Resolutions). Nevertheless, the plan includes a CR assumption of 3 months.

The project has been under formal change control since August 2018. 75 Baseline change Proposals (BCPs) have been processed.

The MC simulation was run on deliverables only, and it supports the funding profile at an 88% CL.

The project provided the BNL EVMS certification DOE letter upon request. It is dated January 21, 2022.7

L2 projects are independent in P6, and there are separate schedules for DOE and NSF scope with the exception of LAr, Common Cost, and PMO which have both DOE and NSF scope with separate control accounts.

The project decided to reset the baseline in April 2022 (BCP-075). The plan is to provide 3 CPRs with the practice baseline before the DOE review

Covid BCPs guidelines are documented in docdb 1269. There have been a total of 4 Covid BCPs. COVID impact through Feb 22 is $10.3M with 8-22 months of schedule delay depending on subsystem.

The RLS is technically driven. The Base Cost/Obligations/Funding shows no pinch points.

CAMs have taken 2-day EVMS training and are required to take a refresher course every year

The project uses the BNL “Integrated Project Database” (IPD), a tool developed at BNL for project management purposes. Interviewed CAMs demonstrated familiarity with this tool.

BOEs have been revised and many quotes updated, some quote updates are still planned before DOE the DOE review to meet the less than a year old quote requirement

M&S traceability tables are included in the BOEs for material over $10k

The schedule quality has been analyzed with Acumen Fuse. Several subsystem schedules show yellow (< 75) scores.

Prior the the DOE review, the project team is planning to refine the Integration and Installation schedule and set up cost accounts

Comments

The project controls team is highly experienced and knowledgeable about the DOE 413.3b system requirements for cost and schedule. They have been practicing EVMS reporting since FY19 and most systems required for CD-2/3 are in place and functioning well. **From the Cost and Schedule perspective, the project is on track for the DOE CD-2/3 review with some opportunities for improvements noted in the comments and recommendations below.**

The project controls team was extremely responsive to our requests for special meetings and information and very helpful.

Schedule quality could be impacting the critical path, float, and simulations. An acumen Fuse schedule quality assessment on the posted file shows 4 out of 8 schedules scores less than 75. There were 133 open ends showing, which can significantly impact float values. There were 321 hard constraints. This makes finding the critical path difficult and skews float numbers. Lower schedule quality impacts accuracy of monte carlo simulations, which is heavily used in determining contingency on this project.

The review team could not replicate the critical path from the posted schedule. This may have been due to technical issues with the export or systems. This made it difficult for the review team to independently replicate the Critical path and integrity of the schedule.

Point adjustments for the baseline use a material resource, which is confusing and will cause inaccurate reporting. Consider using an alternate resource or flagging point adjustment assignments with a code to allow them to be mapped separately.

Currently the team is working on developing an ETC processes/plan. At the moment CAMs are reviewing/updating the ETC as they are statusing the schedule.

WBS elements which are transfers to CERN are not in the WBS Dictionary. Consider adding these transfer CAs to the WBS Dictionary and referencing the WBS which contains the relevant scope.

The 5 CAMs interviewed during drilldowns demonstrated good understanding of their BOEs and schedule and we found them generally very well prepared to manage their accounts after the project is baselined. It is commendable that they showed ownership for the scope under their management. However a few CAMs were not as familiar with some EVMS requirements such as Work Authorization Documents and Freeze Periods. Please continue with CAM drilldown practice sessions prior to the DOE review emphasizing those elements that will be new to them.

The project presented traceability tables for M&S resources which were very helpful, however similar traceability tables for labor resources were not available on all CAs. Labor traceability during drilldowns was cumbersome and should be improved for the DOE CD-2/3 review.

Ensure quotes are no older than a year where possible (there were a few older quotes in the data traces, one over 10 years old).

CAMs interviewed used primarily subjective percent complete to status projects. As the project moves out of design into procurement/installation, review earned value techniques to ensure they use objective measures with Quantitative Backup Documentation (QBD) where possible.

It is important during drilldowns for other members of the project team to avoid interrupting the CAM and answering for him or her, it could send the wrong message to reviewers about lack of confidence on the CAM.

The project uses a less common method for Estimate Uncertainty contingency computation, and some of the CAMs were not very knowledgeable with the process to assign maturity scores to their P6 activities. After some questioning, a mapping table of estimate types to maturity scores was shown by the Project Office. For the DOE review, consider providing a clearer description of the process to assign maturity scores, of the method used by the project to compute estimate uncertainty, and provide a breakdown of estimate uncertainty contingency and risk based contingency to at least to L2 WBS, preferably to L3 WBS. Consider providing a simple table showing the build-up by source.

There are two risk registers. There is a primary risk register and a secondary risk register specific to supply chain risks. Consider combining into a single register to allow for easier review of risks by team.

The current risk analysis indicates that there is insufficient float for the Pixel subproject unless the project team can utilize float held by CERN to meet an 80% CL. Relying on float not owned by the project is a significant concern. This should be further assessed.

The Management Reserve amount specified in the PMP is not consistent with the PEP. Please make sure these documents are consistent. Also, consider revising section in PMP 3.5.2 which seems to indicate small changes can be made to the baseline w/o a BCP. This could be misleading for both reviewers and the project team.

The project documentation system (BNL docdb) is not taking advantage of electronic signatures, which could be a useful feature once the project is baselined to keep track of approved documents. Consider implementing this aspect of docdb.

There is one recommendation from the prior IPR which is still open (assigned to the PM). The recommendation “Before the CD-2/3 Director’s Review, assure project personnel (costed/uncosted) have formalized agreements. “ is in progress. They have started the MOU procedures, about 50% have been signed and the rest are in progress.

The FTE chart at project level indicates about 30 new staff will be needed over the next couple of years. Given the current issues across labs with hiring and retention, consider adding a risk related to impacts from being unable to staff-up in a timely manner.

There is only 10% time for ESH&Q oversight in the schedule. Each Institution has its own ESH&Q resource. This is not in the schedule, but should be covered in the MOUs. Please ensure the ESH&Q effort is fully accounted for in the schedule.

For the DOE review, consider providing a brief navigation document explaining how to perform traceability across schedules, CPR, BOEs and any other documentation. This can help the C&S subcommittee be more efficient with their time.

Recommendations

4) Prior to the DOE CD-2/3 review, consider improving the schedule based on the comments provided above.
5) Prior to the DOE CD-2/3 review, continue practicing drill downs, improve the labor traceability, and ensure CAMs are familiar with the annual bottom-up ETC plan.

8.0 Project Management

Subcommittee: Tom LeCompte* (SLAC), John Carlstrom (U.Chicago), Marc-André Pleier (BNL)

Answers to Charge Questions

4. Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?

Answer: Yes.

5. Does the project understand its dependencies on outside resources such as international collaborators, funding from other agencies, and participation by researchers with other funding sources?

Answer: Yes.

7. Is the documentation required by DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, for CD-2 complete and in good order?

Answer: Yes, but see comments.

8. Are Environment, Safety and Health aspects being properly addressed given the project's current stage of development?

Answer: Yes, but see comments.

9. Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Reviews?

Answer: Yes. Some are still in progress.

3a. Is the documentation required by DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, for CD-3 complete and in good order?

Answer: Yes, but see comments.

Findings

- The U.S. contribution to the HL-LHC consists of upgrades to the accelerator (DOE) and to both ATLAS and CMS (DOE and NSF), totaling ~ $800M. DOE TPC guidance for the U.S. ATLAS HL-LHC Upgrade Project is $195M, including funding for Installation & Integration (I&I) and to compensate for COVID impacts. The corresponding NSF MREFC construction funding is $75M, plus COVID BCPs. Each project deliverable is clearly assigned to a single funding agency.
- The DOE U.S. ATLAS HL-LHC Upgrade Project scope comprises Inner Tracker, LAr and Data Handling. The Inner Tracker silicon accounts for 80% of the DOE subproject base cost.
- BNL hosts the central upgrade Project Office (PO). PO leadership has extensive project management experience from the previous Phase-I upgrade and partially even dating back to the original ATLAS construction. Both NSF- and DOE-funded scope are managed in a fully integrated fashion.
- The PO has incorporated the recent CERN schedule change of Long Shutdown 3 (LS3) – the installation period for the deliverables produced by the project, and the DOE-provided funding profile supports a technically-driven schedule:

US ATLAS HL-LHC DOE Funding Profile	FY21 & Prior	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	Total
TEC	68,000	20,000	27,500	21,100	20,050	12,835	5,000	4,000	-	178,485
OPC	16,515	-	-	-	-	-	-	-	-	16,515
TPC	**84,515**	**20,000**	**27,500**	**21,100**	**20,050**	**12,835**	**5,000**	**4,000**	**-**	**195,000**

- International ATLAS has established a series of reviews before procurements. The various deliverables are in different stages in this process.
- The project plan has been designed to the Objective KPPs (OKPPs). They cover:
  (a) completion of the deliverables, and
  (b) support of I&I activities through LS3.
  The Threshold KPPs (TKPPs) describe completion of the deliverables only.
- Developing memoranda of understanding between the Project and participants are still in progress.
- There was no plenary talk on ES&H.
- The Project practiced regular site visits pre-Covid. Pandemic travel restrictions have caused them to be discontinued.
- Installation and Integration is in objective but not threshold scope, sometimes referred to as “scope contingency”. A 25% contingency is held on these activities.
- A set of planned Key Performance Parameters was shown.

Comments

The presentations were all of very high quality, and we are confident that this project is ready to go forward.

We commend the management team for their close connection to international ATLAS and the funding agencies. This is a strong point of the Management team. We hope and expect this will continue into the future as the project is executed, completed and ultimately the physics potential realized.

Development of MOUs is still in progress. Advancement on this front will help with the upcoming IPR.

A separate plenary ES&H talk would be helpful, and would demonstrate the Project's commitment to ES&H. Having the presentation and HAR reviewed by an external ES&H expert before the October review will help ensure that this goes smoothly.

Site visits are invaluable. The project should restart them as soon as reasonable.

The project documentation will need to be updated before CD-2/3 to properly reflect the project's evolution since CD-1.

General comments on the presentations:

- It was common for talks to use all the assigned time, leaving little time for Q&A. This will not serve ATLAS well at the upcoming IPR.
- Mapping talk slides to charge questions was not always easy. Other experiments put a small flag on each side indicating which charge question is being addressed. (If the answer is "none", that's valuable information to the Project team as well.)
- Be sure all slides are numbered.
- The WBS org charts presented often had the same person listed in many boxes. Rather than wait to be questioned (or risk not being questioned and being dinged later), acknowledge that is the case and explain why it is advantageous, or at least not a problem.
- In several cases, a question to the speaker was answered by their management. While we know Management was only trying to be helpful, the optics of this are not good. It is better to let the presenter "drive" and to chime in only if and when asked.

TRL-6 is a necessary but not sufficient condition to begin production. While an ATLAS level FDR is necessary to start production, it is not a CD-3 requirement. The path to production readiness was shown, but could be emphasized. Uncertainties due to design maturity are acceptable at CD-3, provided they are captured in the risk register and the plan to reach the needed maturity is shown.

The plan to hold I&I as the difference between threshold and objective scope is sensible. The committee understands that meeting only threshold scope has implications for international ATLAS and the operations program, nevertheless, we endorse the prioritizing of detector deliverables over installation. However, a slide explaining this rationale might be prepared in advance to anticipate questions.

The selection of KPPs involves a balance between specificity and the flexibility needed to interact and interface with other stakeholders. There was an opinion that the balance might be tipped slightly too much towards flexibility.

Recommendations

6) Proceed to the CD-2/3 review.

Appendix A - Charge

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June 2, 2022

Director's Review of the U.S. ATLAS HL-LHC Upgrade Readiness for CD-2/3 DOE Review

Charge to the Review Committee

I request that the review panel conduct an assessment of the readiness of the U.S. ATLAS High Luminosity LHC (HL-LHC) Upgrade Project for a CD-2 (Approve Performance Baseline) and CD-3 (Approve Start of Fabrication) combined review to be held by the DOE Office of Project Assessment (OPA) the week of October 17, 2022. This Director's Review will be held remotely on June 27-30, 2022.

The most recent Critical Decisions for the Project were CD-1 (Approve Alternative Selection and Cost Range), approved on September 21, 2018, and CD-3a (Approve Long-lead Procurements), which was approved on October 16, 2019. The project is co-funded by DOE and NSF.

In May 2014, the U.S. HEP program completed its long-term strategic planning through the P5 process. The P5 plan for Energy Frontier recommended that the U.S. actively continue its participation in the LHC program at CERN and, specifically, in the planned HL-LHC upgrades, designating it as the "highest-priority near-term large project." A shutdown of the LHC for the luminosity upgrade is planned to begin in 2026, which will result in the LHC delivering much higher luminosities than have been realized to date, beginning in 2029. The new operating conditions require significant upgrades to the ATLAS subdetectors. The focus of this review is on the DOE-funded scope, which consists of upgrades to the aging ATLAS tracker system (both the strips and pixel subdetectors), the trigger and data acquisition system and the liquid argon calorimeter read-out electronics.

The review committee is requested to perform a general assessment of the project's status and progress, to identify potential issues and to address the following specific questions for CD-2:

1. Does the proposed technical design satisfy the performance requirements? Do the key performance parameters provide a satisfactory indication of the project's completeness?
2. Is the resource-loaded schedule complete, consistent, and credible so that it can serve as cost and schedule part of the project's performance baseline? Is it compatible with the funding guidance provided?
3. Have the project's risks been fully analyzed and accounted for in the contingency estimate?
4. Is the project team properly staffed with individuals that have the required skills to deliver the proposed technical scope within the baseline budget and schedule?
5. Does the project understand its dependencies on outside resources such as international collaborators, funding from other agencies, and participation by researchers with other funding sources?

6. Does the project have a certified EVM system and has the project demonstrated the ability to utilize it as an effective project management tool?

7. Is the documentation required by DOE Order 413.3B Program and Project Management for the Acquisition of Capital Assets for CD-2 complete and in good order?

8. Are Environment, Safety and Health aspects being properly addressed given the project's current stage of development?

9. Has the project responded satisfactorily to the recommendations from the previous DOE Independent Project Review?

The review committee also is requested to address the following questions for CD-3:

1a. Have the final designs been appropriately reviewed by the project and are the designs ready to support fabrication? Was an independent final design review conducted?

2a. Is the planning for major procurements, interfaces between subsystems, and integration of the project adequate to proceed with fabrication?

3a. Has the project met the prerequisites of DOE Order 413.3B for CD-3 and is the required documentation complete and in good order?

The committee report should include comments and recommendations related to the above topics with the goal of improving the readiness of the U.S. ATLAS HL-LHC Upgrade Project for the DOE CD-2/3 review. The final report is requested by Monday, July 11.

I very much appreciate the committee willingness to help with this important review and look forward to reading your evaluation.

Sincerely,

DDenisov

Dmitri Denisov
Deputy Associate Laboratory Director for High Energy Physics, Brookhaven National Laboratory

Appendix B - Review Committee

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