U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Project Assessment
pre-CD-2 Review Report on the

High Luminosity LHC U.S. ATLAS Detector Upgrade (HL-LHC ATLAS) Project

at Brookhaven National Laboratory

January 2022

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the High Luminosity Large Hadron Collider U.S. A Torroidal LHC Apparatus Detector Upgrade (HL-LHC ATLAS) project, located at the Brookhaven National Laboratory (BNL) was conducted remotely, due to the COVID-19 pandemic, on January 25-27, 2022. The review was conducted by the Office of Project Assessment (OPA) at the request of Michael Procario, Director of Facilities for High Energy Physics, Office of High Energy Physics (HEP). The review was chaired by Kurt Fisher, OPA.

The purpose of the review was to assess the status of the HL-LHC ATLAS project with respect to its preparations toward CD-2, Approval of the Performance Baseline, and to determine whether satisfactory progress has been made toward this goal. The ATLAS project team has made good progress since the July 2019 DOE/SC review, especially considering the effects COVID-19 has had on project resources. The Committee offered some general comments on items that could be incorporated to provide clarity as the project team proceeds towards the CD-2/3 Director's Review scheduled for summer 2022. The Committee supported proceeding on the planned path to the CD-2/3 Director's Review.

Silicon Strips

The project team should consider extending the module quality assurance (QA) with testing in a magnetic field as close as possible to the ATLAS field, at varying temperature points between room and operating temperature, in high intensity beams.

Module assembly is on a critical path. With expected changes, there should be just enough float at the time of the CD-2/3 review. However, the project was encouraged to continue to explore ways to expedite module assembly as there may be unforeseen delays in the future.

Stave assembly also does not pose major concerns, but the project team may wish to develop a strategy, with cost impacts, for speeding up the production rate.

Pixels

The Committee agreed with the use of prototype modules made with the RD53A demonstrator chip to validate the serial communication chain proposed to read out the detector.

There are several instances in which deliverables are provided by CERN or external vendors that are therefore outside the direct control of the project. It will be important to understand how delays in deliveries could impact the project schedule and cost.

Although the fabrication of some components is not US scope, it will be important to pay significant attention to QA/quality control (QC) and be able to react to any changes needed:

- For example, the potential for bump bond failures needs to be understood in order to allow time for the flex circuit to be redesigned and tested; and
- The probability of risk RD-06-01-05-004 should be reviewed given that there have already been delays in deliveries from CERN.

The Committee noted that LBNL has not been qualified for module assembly yet.

Global Mechanics

There is one subsystem Final Design Review (FDR) that is not yet completed—the Committee suggested it be completed as soon as possible in preparation for the CD-2/3 review.

There are several Interface Control Documents (ICD) that are not yet completed—the Committee suggested that these documents be completed as soon as possible due to the advanced development status of the global mechanics hardware in general.

The vast majority of the Subsystem 6.03 scope will be completed by the end of FY 2023. Also noted is the fact that the larger project's Integration and Commissioning Subsystem (WBS 6.11) efforts are scheduled to begin ramping up in FY 2023. The anticipated Subsystem 6.11 effort needs appear to be very well aligned with the available skillsets and expertise of the outgoing Integration and System Test team (WBS 6.03.01).

Trigger and Data Acquisition

The progress made by the Data Acquisition (DAQ) team on the technical design is adequate to meet the project's milestone for completion by the proposed CD-2/3 timeframe. Since the July 2019 review, new prototypes for the Global Common Module (GCM; WBS 6.7.1) and Front-end LInk Exchange (FELIX; WBS 6.7.3) have been produced and tested, high-speed link protocols benchmarked, and firmware for data aggregation, clock and busy interface, pixel input/output protocol, and front-end emulator designed and validated.

The project is likely to meet performance requirements and has demonstrated excellent progress in most areas. The only area where technical progress appears to be behind is, where a change from custom hardware to commodity-based solution (WBS 6.7.4.1), endorsed by ATLAS in October 2021, requires a change in the firmware. It should be noted that this is a simplification of the track trigger design and will not negatively impact the project schedule. It will also be cost neutral and allow for a more flexible implementation of the ATLAS track triggers in the processor farm. The Committee supported this change.

The FELIX design is 95% complete and the schedule for its production has a comfortable float of 278 working days to its need-by date. The float should make this deliverable robust against any impacts of supply-chain issues and could potentially accommodate any necessary redesign for a newer generation field programmable gate array (FPGA), next-generation Peripheral Controller Interface (PCI), or unavailable parts.

Liquid Argon (LAr) Calorimeter Electronics

The project team is experienced and has worked successfully together for many years. Progress has been steady and commendable. The preamp/shaper ASIC (ALFE2) will be ready for an FDR this summer and seems to have met specifications. System integration seems well planned.

The schedule for the ALFE2 FDR has slipped from January 2022 to later this summer. Regardless, the Committee judged that the overall task is on a solid path towards completion.

The ALFE2 ASIC has a planned packaging change. The ALFE2 ASIC in the new Ball Grid Array (BGA) package must be thoroughly tested and all electrical specifications verified. This includes tests of all chip interfaces.

Final analysis of recent Single Event Effects (SEE) rad tests on the ALFE2 ASIC must also be completed prior to scheduling the FDR. An acceptable rate should be defined.

The number of ALFE ASICs required by the project is driven by the number of FEB2 boards needed. The FEB2 board spares (~7%) seem to be on the low side, but spare counts match what was done during the original construction. Team members report few failures and seem comfortable with spare counts.

Cost and Schedule

The CERN shift of LS3 start date by an anticipated one year has no impact on the presented schedule, including planned FDRs for each subsystem.

The project team has a clear picture of the next steps to be completed before the CD-2/3 proposed date. The project team is experienced and has robust tools available for execution. However, significant work remains that could require additional help in the area of project controls personnel. The effort to complete the CD-2/3 preparation and the subsequent SPA (schedule = performed work = actuals) process should not be underestimated.

The project presented a resource loaded schedule with constraints and with unclear critical paths. Schedule quality tools (e.g., Acumen Fuse (used by project) and/or Government Accounting Office (GAO) best practice checklist for cost estimating and scheduling) may aid in improving product quality before baselining the project.

The presented resource loaded schedule is not showing clear dependencies to a CD-2/3 approval date on successor/production activities.

The project Risk Register includes risks on the remaining CD-3A scope, but they are not identified explicitly, making the identification difficult for the Committee.

The WBS dictionary is well documented and identifies the collaboration institutions at Level 3.

Inconsistencies between project documents were found. In particular, the project support personnel support in the Project Management Plan (PMP), Primavera (P6), and Basis of Estimate (BOE). Checks/updates are suggested (e.g., the PMP states that WBS 6.10 includes project support staff, but P6 does not).

The project allows for historical earned value COVID-19 changes, which are not in alignment with BNL earned value rules.

The Pixel WBS has 58% of its labor hours as uncosted and the Strips WBS has 41%. Alternative progression techniques should be explored (baseline execution milestones) if standard earned value is not responsive.

Project Management and ES&H

Readiness for CD-2/3 is not only dependent on the U.S. project but needs to be informed by the updated schedule of the international ATLAS project following the CERN modification of the long shutdown (LS3). Socialization of new need-by dates should begin in earnest, with finalization of the need-by dates necessary before final preparation for CD-2/3.

The assumption that COVID-19 impacts on activities/efficiencies will terminate on December 31, 2022, will have to be revisited on the timescale of summer 2022.

Estimate Uncertainty Contingency (EUC) and risk contingency are understandable and appropriately simulated to demonstrate that the present funding level will allow the project to cover existing risks at a an approximately 72% confidence level; however, this appears to be low when compared to standard practices in DOE/HEP projects.

The technical team will need to transition to "project mode" immediately to ensure completion and full embracing of the various project regulating documents (Project Execution Plan, PMP, Quality Assurance Plans, BOEs, etc.). Consistency and cross-checks will require a great deal of work.

The status of Memoranda of Understand/Memoranda of Agreement (MOUs/MOAs) between the project and major institutions is uncertain. Such documents are highly recommended to ensure BNL resources are made available throughout the lifetime of the project.

Key Recommendations

- Before CD-2/3, consider adding a risk (opportunity), with cost impact, that accelerates stave assembly to compensate for upstream delays in order to maintain the current schedule.
- A complete grounding and shielding scheme, including modules, local support structures, and quarter shells, should be prepared in time for the CD-2/3 review.
- LBNL should be fully qualified to assemble modules using the production tooling and present the results at the CD-2/3 review.
- It is recommended that the Global Mechanics Subsystem (WBS 6.03) team pursue with the larger project, the possibility of transitioning available team members into the Integration and Commissioning Subsystem (WBS 6.11) as they roll-off Subsystem 6.03 in an effort to preserve continuity with the project on expertise associated with the general integration and test activities.
- Before the CD-2/3 Director's Review, ensure that WBS 6.7.4.1 is aligned with the approach chosen by the ATLAS collaboration of a commodity-based tracking in the even filter.
- Before the CD-2/3 Director's Review, complete all cost and schedule CD-2/3 requirements and address/document the earned value process related to historical changes.

- Before the CD-2/3 Director's Review, include clear links to successor procurement activities dependent upon the CD-2/3 date.
- Before the CD-2/3 Director's Review, ensure project personnel (costed/uncosted) have formalized agreements.
- Before CD-2/3, ensure all Technology Readiness Level (TRL)-6s are executed, in order to conduct the FDR by the advertised timescale of late spring 2022, irrespective of the expected CERN change in the LS3 schedule.
- Before CD-2/3, consider developing appropriate MOUs/MOAs with all the partner laboratories involved in the project.
- Work with the international ATLAS collaboration to secure an updated ATLAS international schedule as soon as possible, and no later than March 31, 2022.

CONTENTS

Executive Summary i
1. Introduction 1
2. Technical Systems Evaluations ....
    2.1 Science Case/Silicon Strips ....
    2.2 Pixels ....
    2.3 Global Mechanics ....
    2.4 Trigger and Data Acquisition ....
    2.5 Liquid Argon Calorimeter Electronics ....
3. Cost and Schedule ....
4. Project Management and Environment, Safety and Health ....

Appendices

A. Charge Memorandum
B. Review Participants
C. Review Agenda
D. Cost Table
E. Schedule Chart
F. Funding Table
G. Management Chart

1. INTRODUCTION

The ATLAS (A Toroidal LHC Apparatus) Experiment is a seven-story, 7,000-ton multi-purpose detector system located at the European Organization for Nuclear Research (CERN) laboratory in Geneva, Switzerland. The ATLAS Detector, and the other general-purpose CMS detector, are situated at the Large Hadron Collider (LHC), the world's highest energy accelerator currently in operation. The experiment probes the fundamental forces of nature in proton-proton collisions at the energy frontier of particle physics, a regime that offers unique opportunities for seminal discoveries in basic physics.

The LHC provides access to new physical phenomena, some predicted by promising theoretical models, which would manifest themselves as heretofore unobserved states, including: supersymmetric particles, manifestations of technicolor or extra dimensions, new gauge bosons, or evidence of compositeness of quarks or leptons. The discovery in 2012 of a Higgs boson at CERN was a striking achievement, representing a multi-decade world-wide scientific campaign to understand the basic forces that govern our physical world. Its observation offers the opportunity to further study the origin of electroweak symmetry breaking and other elemental phenomena through precision measurements of the Higgs boson's properties, including its couplings to other particles, self-couplings, and rare decays.

In May 2014, the U.S. HEP program completed its long-term strategic plan through the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP). 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 High Luminosity LHC (HL-LHC) upgrades, designating it as the "highest-priority near-term large project".

The U.S. participation in the ATLAS experiment has been crucial to its success. The U.S. ATLAS collaboration makes up about 19% of the entire ATLAS collaboration. U.S. groups have made significant contributions to nearly every aspect of the detector throughout all phases including construction, installation, and preparation for data taking. ATLAS personnel is supported as part of the Department of Energy (DOE) High Energy Physics (HEP) research program; the National Science Foundation (NSF) Elementary Particle Physics Program; and the U.S. ATLAS Operations Program, which is jointly funded by DOE and NSF.

The LHC successfully completed its initial three-year run in 2012 at center-of-mass energies of 7 and 8 Tera-electron Volts (TeV), reaching a peak luminosity of 7.7×10^{33} $cm^{-2}s^{-1}$, and resumed operations in 2015 at an energy of 13 TeV with planned increases to luminosities of $2\text{-}3 \times 10^{34}$ $cm^{-2}s^{-1}$ through 2023. A High Luminosity upgrade of the LHC is planned to begin operations in 2029 with levelled luminosities reaching $5\text{–}7.5 \times 10^{34}$ $cm^{-2}s^{-1}$, 5–7.5 times the design luminosity, and corresponding to 140 to 200 interactions per crossing (pile-up) with 25 ns bunch spacing operations. Such pile-up conditions are expected to be factors of 5-8 times higher than those presently seen at the LHC. To operate for an additional decade within the challenging environment, the ATLAS detector requires upgrades to an aging tracker system, the calorimeter and muon system readout electronics, and the trigger and data acquisition system. Additionally for the first time in a collider experiment, a timing detector will be added.

The High Luminosity LHC U.S. ATLAS Detector Upgrade (HL-LHC ATLAS) project is designed to enhance the detector capability for the high luminosity data run that is scheduled to begin in 2029.

Upgrades are needed to four detectors where the U.S. played a leadership role in the original construction: replacement of the Inner Detector (ID) by the ITk, replacement of the Liquid Argon (LAr) and tile (TILE) calorimeter readout electronics, new muon system chambers and electronics (MUON), and overhaul of the Trigger and Data Acquisition (TDAQ) system.

Inner Tracking (ITk) Pixel Detector: The U.S. (DOE) will deliver the Inner Pixel system, comprising the innermost two pixel layers and their services. Inclined Pixel modules will be used in the outer barrel region of the ATLAS detector. However, in the innermost layers (Inner System), this geometry leads to complications in the thermal properties of the system and in the routing of services. U.S. groups proposed an alternative option in the Pixel Technical Design Report (TDR) in which inclined modules are replaced with rings. The design of the local supports is much simplified (making the construction much simpler) and the services can be more efficiently routed outside the volume. Preliminary simulation studies show no physics performance degradation versus the baseline inclined option. A formal choice of the inner system design was be made in summer 2018 after optimization of the alternative layout. Readout data rates for the innermost layers of the pixel system are extremely large, which has led to a design of the pixel front-end readout chip that can transmit data at 5.12 Gb/s. Transferring this data over several meters require the use of special, low mass, radiation hard, data cables. Several potential options were considered, and the U.S.-developed twinax cable solution was chosen as the baseline for the TDR.

ITk Strips Detector: The US (DOE) will deliver half of the barrel strip detector and its services. The strip system consists of four barrel layers and six disks in the forward region. The corresponding area of silicon sensors, at 165 m^2 corresponds to 2.5 times that of the current Inner Detector silicon strip system. The target acceptance has been extended to ± 4 units of pseudo-rapidity and the number of pixel layers, the outer radius of the pixel array and its corresponding area have all increased. The new detector layout results in a lower inactive material in the tracking volume (comprising less than one radiation length up to a pseudo-rapidity of 2.7) and gives a performance that is as good and, in many cases, better than the existing detector, but in a much more difficult tracking environment with up to an average of 200 proton-proton interactions per beam crossing. The ITk has been designed with efficient pattern recognition and track reconstruction in mind to give high track reconstruction efficiency and a low rate of fake tracks (even at HL-LHC pile-up levels). For muons with transverse momentum above 3 GeV this means greater than 99% efficiency; with efficiencies of greater than 85% for pions and electrons above 1 GeV out to a pseudorapidity of 2.7, while keeping fake rates below 1%. In addition, the performance is shown to be robust against a 10% loss of channels or modules that might occur as a worst case over the lifetime of the experiment.

ITk Global Mechanics: The U.S. (DOE) will develop and produce mechanical support structures for the ITk.

DAQ and Data Handling: The U.S. (DOE) will develop and produce the Global Common Module (GCM) electronics board for the Global Trigger and develop elements of the common readout system (FELIX) for the HL-LHC ATLAS project.

Liquid Argon (LAr) Calorimeter Electronics: The U.S. (DOE) will develop the LAr preamp/shaper ASICs (application-specific integrated circuits) and lead LAr electronics integration efforts.

Several alternatives to the current baseline design of the LAr preamp/shaper ASIC have been considered. Initial studies were made that investigated using the SiGe (silicon-germanium) process for the chip, and sufficient progress was made to consider this as a viable backup option. However, the baseline design uses a complementary metal-oxide-semiconductor (CMOS), which requires lower power—a significant issue for front-end electronics cooling. The chip is implemented using the 130 nm Taiwan Semiconductor Manufacturing Company (TSMC) process and is at the final prototype stage.

The excellent performance of the LHC so far and the experience gained from ongoing analysis of data taken at lower luminosities, and from special high pile-up runs produced by the LHC machine group, along with studies of simulated data for expected higher luminosities, has helped ATLAS plan for upgrades at the higher luminosity that will be needed to search for new physics with high efficiency. The overall ATLAS physics program can only succeed if the necessary upgrades are implemented; thereby ensuring that high efficiency for expected physics is maintained as energy and luminosity increase beyond current design.

As with the U.S. participation in the construction of the original ATLAS detector, the ATLAS Upgrade will be funded jointly by DOE and NSF. The scope has been divided between the agencies in a manner that minimizes the inter-agency dependencies. The fractional cost sharing will be approximately 66% from DOE and 33% from NSF. DOE approved Critical Decision (CD) 0, Approve Mission Need, for HL-LHC ATLAS on April 13, 2016; and CD-1, Approve Alternative Selection and Cost Range, on September 21, 2018; and CD-3A, Approve Long Lead Procurement of Early Production Components, on October 15, 2019.

Now, early in 2022, an Independent Project Review was conducted by the DOE/OPA (via zoom due to COVID-19 pandemic constraints) on January 25-27, 2022, to assess the project's progress in preparation for CD-2/3 which is anticipated later this year.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Science Case/Silicon Strips

2.1.1 Findings

The ATLAS inner detector (pixels, current silicon microstrip (SCT), and transition radiation tracker (TRT)) will be replaced with a full silicon-based tracker including the ITk pixel and the ITk strip detectors (strips) to cope with the increased radiation level (corresponding to 4000/fb of pp collisions) and instantaneous luminosities (up to $7x10^{34}$ $1/cm^2s$) expected at the HL-LHC. The sensor and module design, readout, detector layout, cooling, and power scheme are optimized to provide efficient object reconstruction and identification.

The U.S. ATLAS ITk strips Key Performance Parameter (KPP) is the delivery of 50% of the barrel strip detector, in the form of 196 “staves”, which meet the ATLAS performance specifications. A stave is composed of a stave core (a carbon fiber/carbon foam composite with embedded cooling to provide mechanical support and thermal stability), mounted with 28 modules (where a module is a silicon sensor with one or two hybrids carrying readout and control ASICs) and associated power supply and monitoring electronics.

The WBS structure mirrors the assembly of staves, as follows:

- Stave Core (WBS 6.02.01)—this scope of work assembles the stave cores from carbon fiber and carbon foam components, with the embedded bus bars to provide connection from the end-of-service card to the modules.
- Readout Electronics (WBS 6.02.02)—this scope of work designs and fabricates the module electronic components, in particular the readout ASIC ATLAS Binary Chip (ABC*), data concentrator Hub Hybrid Controller Chip (HCC*), slow control chip Autonomous Monitor and Control Chip (AMAC), high voltage multiplexer chip, and the power board to supply low and high voltage to the module. In addition, there is a contribution to COST power supplies.
- Module (WBS 6.02.04)—this scope of work assembles and tests all the hybrids, including loading the ASICs and associated surface mount components and testing the bare hybrid before delivery to module assembly; it also assembles sensors and hybrids into modules and performs quality control (QC) testing before delivery to stave assembly.
- Stave Assembly (WBS 6.02.05)—this scope of work assembles 28 modules onto staves and performs QC testing and delivers to CERN.
- US Contributions to CERN (WBS 6.02.07)—this WBS captures the contributions to CERN procurements, chiefly in ASICs, and optical and power conversion components.

With the exception of the silicon sensors, the project is deeply embedded in the design process and fabrication of all the components, as well as stave assembly and shipment to CERN. The KPPs are unchanged with respect to the July 2019 review. The objective KPPs include: a) fabricate, test, and deliver to CERN the staves for one-half barrel of the silicon strip detector consisting of both short- and long-strip modules, constructed to ATLAS specifications, and b) participate in the integration, testing, installation, and commissioning of the silicon strip detector at CERN. The threshold KPPs are: a) fabricate, test, and deliver to CERN the staves for one half- barrel of the silicon strip detector consisting of long-strip modules, constructed to ATLAS specifications, and b) prepare for the integration and testing of the silicon strip detector at CERN. Moving from the objective to the threshold KPPs would lead to savings of up to $1.6 million and up to five months contraction of schedule.

The Baseline at Completion (BAC) estimate for the strip detector is $45.549 million, an increase of $7.1 million since CD-3A, and the largest of the Level 2 areas. It is comprised of 58.6% labor, 40.2% material and supplies, and 1.2% travel. The breakout at Level 3 is shown in Table 2.2-1.

Table 2.2-1. L3 Breakdown of BAC for Strips, by Labor, Material, and Travel

WBS L3	Labor	M&S	Travel	Total	Fraction
6.02.01 Stave Core	43.5%	56.2%	0.2%	7,998,685	18%
6.02.02 Readout Electronics	54.8%	44.6%	0.6%	6,576,416	14%
6.02.03 Hybrid Assembly	63.0%	37.0%	0.0%	1,229,940	3%
6.02.04 Modules	79.7%	17.9%	2.3%	18,525,578	41%
6.02.05 Stave Assembly	62.1%	37.2%	0.7%	6,540,931	14%
6.02.07 US Contributions to CERN Procurements-BNL	0.0%	100.0%	0.0%	4,677,744	10%
Grand Total	**58.6%**	**40.2%**	**1.2%**	**45,549,294**	

The cost-and-schedule evolution was presented including technical driven and COVID-19 driven Baseline Change Proposals (BCP):

Table 2.2-2 Baseline Change Proposals

WBS	July 2019 in k$	Regular BCPs in k$	% change Reg. BCPs	COVID BCP in k$	% change COVID BCPs	Delay (COVID) in months
Cores	$5,418	$1,695	31%	$284	5%	23 (11)
RE	$5,587	$460	8%	$523	9%	21 (11)
Hybrid+Modules	$16,728	$1,286	8%	$1,741	10%	19
Stave Assy	$6,159	-$98	-2%	$479	8%	19
CERN Purchases	$4,525	$152	3%	$0	0%	
Total	**$38,417**	**$3,495**	**9%**	**$3,027**	**8%**	**19**

The project team optimized the usage of human, financial, and technical resources leveraging the expertise at both national laboratories and universities. Three sites are foreseen for hybrids and modules construction to guarantee redundancy and meet the assembly throughput requirement; one site is foreseen for stave assembly to minimize capital investment in equipment. Much of the required infrastructure for the particular task already exists at the relevant site. Universities and laboratories with historical expertise in front-end electronics have been selected to lead the development of the electronics (and contributed to the DAQ for testing).

Overall scientific labor is 40% of the total labor to go, and varies depending on the Level 3 area. A risk associated with the loss of support is included in the project risk registry and included in the cost estimate.

Since the July 2019 review, the project has completed the prototyping phase and entered the pre-production phase. During the pre-production phase, the project prepared to build two full staves with functional modules using some pre-production components (ABC* ASIC, sensors, bus tapes, etc.). The last phase of the pre-production (first to third quarter CY 2022) foresees the assembly of seven staves. A subset (or all) of the staves will use the final pre-production components (including the HCC*, AMAC). Production will start in late CY 2022.

The ASICs are currently on the critical path. The final version of the ABC* has been received, tested, and used for module assembly. Preliminary testing of the recently received HCC* and AMAC ASICs are very promising. Irradiation tests are planned for early spring 2022.

The project passed all Final Design Reviews (FDR) and two of the Production Readiness Reviews (PRR). The missing PRRs are expected in spring-fall 2022.

Work is performed complying with the local ESH policies.

Sites are fully qualified (or very closed to be) for sensor QC, hybrids, and module assembly. Core staves and stave assembly will start the qualification process soon.

The project is exercising procurement with the final vendors while mitigating the risks of using one single vendor (e.g., bus tapes).

Due to the pandemic, and a number of risks have been realized since 2019, the cost of the project has increased by approximately $3.5 million plus approximately $3.0 million, respectively. There is an additional $600,000 increase in the BAC that migrated from common funds into strips, thus not affecting the total project TPC.

The project, together with the international project, is exploring options to increase the float, currently at negative one month. Under the assumption of the new CERN schedule, increased rate of module production, earlier delivery of components, the float becomes 17 months. This is still smaller than the needed float resulting from simulation studies (19 months). The latter will be reduced by approximately six months once the risks associated with the ASICs are retired.

2.1.2 Comments

The Committee commended the project for the technical progress of the past two years, the comprehensive and well-structured presentations, the associated documentation, and for having provided answers during the breakout sessions.

The two-year saga regarding radiation robustness of the HCC* appears to be converging. Results with irradiation tests scheduled imminently are critical to retire substantial risks and ensure that the expected level of readiness for CD-3 is achieved.

The modules assembled during the prototyping and preproduction phases meet the technical specification and thus demonstrate that the module assembly is ready for CD-3. The Committee encouraged the project team to consider extending the module QA with testing in a magnetic field as close as possible to the ATLAS field, at varying temperature points between room and operating temperature, in high intensity beams.

Module assembly is on a critical path. With expected changes, there should be just enough float at the time of the CD-2/3 review. However, the project is encouraged to continue to explore ways to speed up as there may be unforeseen delays in the future.

Overall stave cores seem well prepared; however, the recent change in vendor availability for bus tapes is concerning. The proponents are aware of this and have a reasonable plan, but this should be followed carefully to a resolution.

Stave assembly also does not pose major concerns, but may wish to develop a strategy, with cost impacts, for speeding up the production rate.

The project addressed recommendations from previous reviews in a satisfactory manner.

While technical readiness for CD-2/3 is evident, preparation of the materials and the presentation of the case was not as evident—inconsistencies in documents and lack of crisp messaging hampers an otherwise strong case for CD-2/3. Fixing this requires a significant time investment and high priority for the entire team, which starts immediately.

2.1.3 Recommendations

1. Before CD-2/3, consider adding a risk, with cost impact, that accelerates stave assembly to compensate for upstream delays to maintain the current schedule.

2. In preparation for CD-2/3, complete and cross-check the entire documentation base, including BOEs, QA/QC documents, risk documents, and presentations, to ensure consistency and strengthen the presentation of the case for CD-2/3 approval.

3. Continue to the CD-2/3 Director's Review.

2.2 Pixels

2.2.1 Findings

The U.S. deliverable for the HL-LHC ATLAS pixel upgrade is the fully integrated inner system made of 12 independent quadrants that include all active detectors, are fully loaded and tested, and shipped to CERN with all electrical, optical, and cooling services, as well as power supplies. In total, the US will deliver 800 modules for instrumenting layer 1, which comprises 69% of the total number of layer 1 modules needed to build the detector. The Committee noted that the detector is designed to operate for at least 2000 fb^{-1} while the entire HL-LHC program foresees 3000-4000 fb^{-1} of delivered luminosity, and that the detector must be designed to be replaceable. The perceived limitation is the radiation hardness of the front-end chip and since the choice of sensor for the inner-most modules is one made using 3D implants, they will likely survive for the entire HL-LHC program. A proper radiation hardness evaluation of the performance of fully assembled modules will be necessary to establish the likely lifetime of the detector. Adequate attention has been given to ES&H procedures, and these are found to be well embedded in all developments and assembly processes.

2.2.2 Comments

The Committee encouraged the project team to continue integration of production parts into horizontal slice tests when possible but recognized the adequacy of using the RD53A demonstrator chip to validate the serial communication chain. The Committee judged that the current program of R&D and pre-production appears to be adequate for addressing most of the outstanding technical risks, but in some cases could be described in more detail. In particular, the way in which the detector would be removed was not described, nor were the methods to be used for transporting large-scale components to CERN once assembled and tested in the US. It was also noted that the impact of descoping the detector coverage to pseudo-rapidity $|\eta|<3$ in terms of project cost and schedule, as well as the timing of such a decision, could have been better highlighted.

One concern identified by the Committee was the reliance on external partners, which include CERN, various vendors, and international universities, for the delivery of components needed for detector assembly. Delays in delivery could potentially delay the US project and the impact of such delays should be described in more detail. Nevertheless, the Committee judged that the project team was working closely with these external partners and would have advanced warning of possible delays and may be able to react accordingly. Given that CERN has already been late delivering readout chips, the Committee encouraged the project team to revisit the probability of risk RD-06-01-05-004 (delays from international collaboration). Likewise, the US project team will be performing important QC on externally provided components, such as hybrid pixel modules, and will be able to respond quickly to any problems encountered with upstream suppliers. For example, bump-bonding failures in hybrid pixel modules will need to be understood in detail to allow sufficient time to re-design the associated flex circuit if necessary. Finally, although Berkeley is planned to be one of the module assembly sites, it was noted that at the review they had not yet assembled a module using the tooling developed for this purpose.

2.2.3 Recommendations

4. The full readout chain should be exercised with final and close to final components as soon as they become available and in time for the CD-2/3 review.

5. A complete grounding and shielding scheme, including modules, local support structures and quarter shells, should be prepared in time for the CD-2/3 review.

6. At the next review, present a detailed plan for QA/QC of module components, modules, and larger systems during production.

7. Berkeley should be fully qualified to assemble modules using the production tooling and present the results at the CD-2/3 review.

2.3 Global Mechanics

2.3.1 Findings

A significant portion of the Global Mechanics (WBS 6.03) had already passed a CD-3A level review. The subsystem in general is quite well advanced in working towards CD-2/3. At the time of this review, the work completed is roughly $10.4 million of a total budget of $16.1 million.

The subsystems programmatic Cost and Schedule Performance Indices (SPI/CPI) are both above 0.90 and appear to be on a trajectory to improve further.

A Monte Carlo Analysis of the current Risk Register indicates with a 90% confidence level that Global Mechanics completion will draw less than $2.1 million on contingency in order to reach completion. This is an appropriate amount (37%) based on the approximate $5.7 million in work remaining.

There were significant increases to the baseline budget from 2019 to the baseline budget in 2021 (49% increase). This increase was larger (fractionally) than any other subsystem. A breakdown of all the contributions to this increase indicate that the increase is well justified.

The completion dates for the Global Mechanics major deliverables were examined with respect to their anticipated need times at CERN. All the associated floats appear to be at comfortable levels.

The project team has put in place an extensive set of Interface Control Documents (ICD) as identified by an N^2 diagram. Sixteen of these ICD documents are completed and four remain to be completed.

The project team experienced a setback with a cracked composite shell early in the fabrication stage. The design of the element (thin shell with external stiffeners) was such that this event was not catastrophic, and a simple repair was successfully undertaken. The project team was very quick to recover and move forward.

Impacts due to COVID-19 have been realized and are estimated to be approximately 24% ($1.3 million) of the total cost increases since the 2019 CD-3A baseline was established.

2.3.2 Comments

There is one subsystem FDR that is not yet completed, and it was suggested that this be completed as soon as possible in preparation for the CD-2/3 review.

There are several ICD documents that are not yet completed, and it was suggested that these documents be completed as soon as possible due to the advanced development status of the Global Mechanics hardware in general.

The vast majority of Global Mechanics scope will be completed by the end of FY 2023. Also noted is the fact that the larger project's Integration and Commissioning Subsystem (WBS 6.11) efforts are scheduled to begin ramping up in FY 2023. The anticipated Integration and Commissioning Subsystem effort needs appear to be very well aligned with the available skillsets and expertise of the outgoing Integration and System Test (WBS 6.03.01) team.

2.3.3 Recommendation

8. It was recommended that the Global Mechanics (WBS 6.03) team pursue with the larger project, the possibility of transitioning available team members into the Integration and Commissioning (WBS 6.11) as they roll off Global Mechanics in an effort to preserve continuity with the project on expertise associated with the general integration and test activities.

2.4 Trigger and Data Acquisition

2.4.1 Findings

The trigger and data acquisition (TDAQ) system for the ATLAS HL-LHC project focuses on the detector readout and trigger data preparation, with the goal of achieving Level-0 trigger rates at 1 MHz with 10 us latency and event filter output rate of 10 kHz.

It consists of three deliverables: WBS 6.7.1 for hardware and firmware design of the Global Common Module (GCM); WBS 6.7.3 for hardware and firmware design of the Front-End LInk Exchange board (FELIX); and WBS 6.7.4 for firmware design for the interfaces between GCM and FELIX, and the implementation of the track trigger interface at the event filter. This last component has changed its implementation from a custom design hardware interface to a commodity-based interface.

The deliverables are under the responsibility of BNL (WBS 6.7.1 and hardware component of WBS 6.7.3) and ANL (WBS 6.7.4 and firmware component of WBS 6.7.3). They heavily rely on the expertise built by these two groups during the design of ATLAS Phase I upgrades. The fraction of deliverables, which are US-ATLAS vs. international partners responsibility, is about 70% for the hardware design and between 30% to 100% for the firmware.

The GCM is an ATCA blade with more than 100 optical links from 9.6 Gbps to 25 Gbps each. US-ATLAS is responsible for designing the hardware and delivering 18 of the 54 modules needed. A second GCM prototype was completed in December 2021 featuring 2 Xilinx Ultrascale+ VU13P field programmable gate array (FPGA) as functional units, a Xilinx ZYNQ+ Soc FPGA for controls, and Samtec 28G Firefly modules at the new 3.8V required voltage for fiber interface. The board was successfully tested with fibers running the 25 Gbps Interlaken protocol, and the firmware for the data aggregation and multiplexing unit integrated. The FELIX is a Gen4 PCIe card with 24 optical links running up to 9.6 Gbps. US ATLAS is responsible for designing the hardware and delivering 205 of the 584 cards needed in the final system. A first prototype using the Xilinx VM1802 FPGA was produced. All design functionalities were verified, including firmware for the clock and busy signal distribution, pixel

I/O protocol and front-end emulator. The prototype was distributed to international collaborators for confirmation of performance with full firmware and software.

The Readout Interface firmware is a new addition to the ATLAS TDAQ architecture. Progress has been reported on the 25 Gbps link interface between GCM and Felix. Firmware for track identification using the Hough algorithm has been developed in 2021 and used in the decision to move to a commodity-based solution for the ATLAS event filter tracking. The firmware is expected to have efficiency greater than 98% for muons with $p_T > 1$ GeV according to simulations. It is also expected to achieve the 500 MHz timing needed to meet the Gen4 PCIe specifications.

The GCM hardware is 70% complete with the specification review (SPR) due in January 2022 and Preliminary Design Review (PDR) planned for October 2022. The FELIX hardware is 95% complete with the PDR scheduled for January 2022 and the FDR for first quarter 2023. For the GCM-to-FELIX interface firmware, the PDR is planned for October 2022.

The total cost for the HL-LHC ATLAS TDAQ is close to $13 million, back-loaded because of large quantity board production in FY 2023-2024. There is an increase of about $1 million from CD-3A due to new quotes for parts, additional task added to GCM power tests at BNL since international travel was not possible, and corrections of errors found in the resource loaded schedule.

The GCM and FELIX procurements and productions are handled through CERN but are quoted in US Dollars, which limits the exposure to currency fluctuations. Needed at CERN dates range between February and December 2026. The critical path runs through WBS 6.7.1 with 243 days of float (was 257 days at 2019 review).

The highest ranked risk is loss of key personnel. Mitigation is in place in the form of sharing board design expertise among a large group of engineers. A second highest risk coming from changes in ATLAS requirements is expected to decrease once the GCM passes SPR. External dependencies coming from hardware and firmware shared among international collaborators are captured in the risk register.

The threshold KPPs are met with a combination of GCM and FELIX boards delivered to CERN in a quantity that is about 50% of the objective KPPs (with identified Phase I boards to make up for the difference), and with a limited participation in the integration, testing, installation, and commissioning of the DAQ system.

2.4.2 Comments

The progress made by the DAQ team on the technical design is adequate to meet the project's milestone for completion by the proposed CD-2/3 timeframe. Since the July 2019 review, new prototypes for GCM (WBS 6.7.1) and FELIX (WBS 6.7.3) have been produced and tested, high speed link protocols benchmarked, and firmware for data aggregation, clock and busy interface, pixel input/output protocol and front-end emulator designed and validated.

The project is likely to meet performance requirements and has demonstrated excellent progress in most areas. The only area where technical progress appears to be behind is WBS 6.7.4.1, for which a change from custom hardware to commodity-based solution, endorsed by ATLAS in October 2021, requires a change in the firmware. It should be noted that this is a simplification of the track trigger design and will not negatively impact the project schedule. It will also be cost neutral and allow for a more flexible implementation of the track triggers in the processor farm. The Committee supported this change.

The project conducted thermal simulations and measurements for the current GCM design for different power loads. The project team should ensure that the final design, under maximum expected power and realistic conditions, adheres to component specifications for maximum operating temperature.

The GCM team envisions a move from the current Xilinx Ultrascale+ FPGA to the latest generation versal premium series FPGA for its final design. This will double the resources available to global trigger algorithms. Although the rest of the components would remain the same, the Committee noted that the redesign of the board needed for replacing two large FPGAs may have a significant impact on the routing. Should the additional design, testing cycle, and availability of parts conflict with meeting the final production scheduled for completion in 2024, the Ultrascale+ version would be a natural fallback.

The FELIX design is 95% complete and the schedule for its production has a comfortable float of 278 working days to its need-by date. The float should make this deliverable robust against any impacts of supply-chain issues and could potentially accommodate any necessary redesign for a newer generation FPGA, next-generation PCI, or unavailable parts.

The project team has substantial management experience, design skills, laboratory and engineering support to produce credible technical, cost and schedule estimates. The deliverables in most cases are an evolution of similar work done for the Phase 1 upgrade.

The project team understands well the dependencies on outside resources and has done an excellent job of managing and mitigating the risk associated with these dependencies. Most of these outside contributions are in the form of engineering labor and design, and the project team works closely with the relevant institutions to manage the work and understand the progress. Nevertheless, risks remain and will need to be closely managed in the future.

The current supply chain effects from the COVID-19 induced crisis in the semiconductor industry pose challenges to the DAQ subproject hardware deliverables in acquisition of FPGAs, optical modules, and even printed circuit boards. The project team is doing a good job of managing supply challenges, monitoring the status and keeping in close touch with key vendors. They are identifying, testing, and estimating the impact of alternatives to the current baseline components and solutions.

The DAQ team has a good understanding and is properly addressing the ES&H aspects of the project. This includes the safety aspects of high-performance electronics such as fire risk and the impact of sound noise levels, as well as accounting for COVID-19 restrictions in accessing the workplace.

2.4.3 Recommendation

9. Ensure that WBS 6.7.4.1 is aligned with the approach chosen by the ATLAS collaboration of a commodity-based tracking in the Even Filter before moving to CD-2/3 Director's Review.

2.5 Liquid Argon Calorimeter Electronics

2.5.1 Findings

The HL-LHC upgrade for the Liquid Argon (LAr) readout system encompasses five components, including:

1. An Analog-to-Digital Converter and Optics front-end system (ADC; WBS 6.4.1)
2. An upgraded version of the front-end board (FEB2; WBS 6.4.2)
3. The LAr Signal Processor (SRTM; WBS 6.4.3)
4. The system integration of these items (WBS 6.4.4)
5. The development of a preamp/shaper circuit (WBS 6.4.5)

The system integration and preamp/shaper development are conducted under DOE scope.

The preamp/shaper ASIC passed a Preliminary Design Review (PDR) in December of 2020. The FDR is scheduled for later this summer. This represents a six-month slip from the previous schedule. The preamp/shaper ASICs (ALFE2) were manufactured in spring 2021 and tests so far show ASIC is performing according to specifications.

A Ball Grid Array (BGA) packaging solution of the ALFE2 ASICs is underway.

A production test plan utilizing robotic test systems at both BNL and TJNAF is progressing.

The preamp/shaper design team continues to support the production and testing phase. Additional manpower required for testing has been planned.

The system integration testing will include performance/compatibility tests of the front-end, BE, DAQ, and calibration/timing/trigger components.

System integration also covers the QC testing of 50% of the production FEB2 boards. The remaining boards will be tested by French collaborators.

A total of 1,524 (on detector) plus 103 (spare) FEB2 boards will be produced. This represents 7% FEB2 spares. There is a plan for a minimum of additional 6% spare ALFE ASICs.

A set of test boards has been designed to stand in for production boards until they are available. This will allow system integration to move forward in absence of any particular board(s).

2.5.2 Comments

The project team is experienced and has worked successfully together for many years. Progress has been steady and commendable. The preamp/shaper ASIC (ALFE2) will be ready for FDR this summer and seems to have met specifications. System integration seems well planned.

The schedule for the ALFE2 FDR has slipped from January 2022 to later this summer. Regardless, the Committee judged that the overall task is on a solid path towards completion.

The ALFE2 ASIC has a planned packaging change. The ALFE2 ASIC in the new BGA package must be thoroughly tested and all electrical specifications verified. This includes tests of all chip interfaces.

Final analysis of recent Single Event Effects (SEE) rad tests on the ALFE2 ASIC must also be completed prior to scheduling the FDR. An acceptable rate should be defined.

Design of a robotic system is underway to test approximately 78K ALFE ASICs. Given the number of parts to be tested, this system plays a vital role and progress should be closely monitored. The ALFE2 test board will need to be modified for the new BGA package and parameters for determining ASIC pass/fail criteria must be established and documented.

The number of ALFE ASICs required by the project is driven by the number of FEB2 boards needed. The FEB2 board spares (approximately 7%) seem to be on the low side, but spare counts match what was done during the original construction. Team members report few failures and seem comfortable with spare counts.

System integration tests exercise all board-to-board interfaces and will use production boards or prototype/emulator boards when production boards are not yet available. This will be a dynamic and flexible test stand and configurations will change as production boards become available. It will be important to make sure that sufficient resources are allocated to keep up with hardware, firmware, and software changes.

Whenever possible, the system interface test stand should use the same type of power supplies and cables which are utilized in the final system.

2.5.3 Recommendation

10. Proceed to CD-2/3 Director's Review upon completion of ALFE2 ASIC FDR.

3. COST and SCHEDULE

3.1 Findings

PROJECT STATUS		
Project Type	MIE	
CD-1	Planned: 9/2018	Actual: 9/2018
CD-3A	Planned: 10/2019	Actual: 10/2019
CD-2/3	Planned: 10/2022	Actual: TBD
CD-4	Planned: 9/2029	Actual: TBD
TPC Percent Complete	Planned: 45%	Actual: 41.2%
TPC Cost to Date	$58.2M	
TPC Committed to Date	$62.6M	
TPC	$181M	
TEC	$154.5M	
Contingency Cost (w/Mgmt Reserve)	$39.5M	53.8% to go
Contingency Schedule on CD-4b	30 months	50%
CPI Cumulative	0.92	
SPI Cumulative	0.93	

The project received approval for CD-0 in April 2016, CD-1 in September 2018 and CD-3A in October 2019.

The DOE TPC guidance for HL-LHC ATLAS is $181 million; NSF (construction funding) TPC guidance is $75 million. The DOE project has 53.8% of contingency for work to go.

The DOE CD-3A approved long lead procurements in the strips (11) and global mechanics (4). The CD-3A approved portion was $8.9 million, including contingency $12.6 million. Vendor delays and cost increases had a significant impact on the CD-3A execution. The contingency is presently 27% on work to go. Since 2019, CD-3A scope was expanded by approximately $283,000 via a Baseline Change Proposal (BCP), currently under approval.

Scope contingency is approximately $6 million, and it corresponds to a reduced numbers of items (i.e., reducing pixel coverage, reducing number of GCM boards, etc.). The scope contingency is not including the project support to Installation and Commissioning (I&C). If the CERN installation schedule will be further delayed, DOE will decide if the project could proceed to CD-4 and this amount could be transferred to operation.

The resource loaded schedule developed is technically driven, within cost range and following the current funding guidance. Continuing resolution is also taken into account, such as major contracts are not planned to start in the first quarter of any fiscal year.

There are eight independent resource loaded schedules for each Level 2 WBS with independent critical paths.

The resource loaded schedule is presently aligned with the CERN LS3 starting dates in January 2025. The project highlighted that there will be a high probable shift of the LS3 starting date from January 2025 to January 2026. External dependencies are captured in the resource loaded schedule as constrained milestones.

Some labor rates are recently updated, and work is ongoing to update the remaining labor rates and it is presented to be completed for CD-2/3 review. Updated rates are expected to have more than 5% discrepancy with respect to the present ones.

I&C activities are represented by planning packages in the resource loaded schedule.

The Monte Carlo risk analysis is performed for the risks applied to the production part of the schedule. There are not risks in the risk registered identified for the I&C scope. The Monte Carlo risk analysis results are relevant for the thresholds KPPs.

There is not a separate risk analysis for the CD-3A remaining work. However, there are risks identified in the Risk Register for the remaining CD-3A scope.

The COVID-19 analysis has been presented and it does not extend beyond FY 2022. The remaining COVID-19 cost is evaluated at $8.375 million to be applied in the future activities.

The project is using different Primavera (P6) calendars to represent COVID-19 labor inefficiencies; is using FY 2019 as base cost year, and de-escalates current quotes to FY 2019.

Support personnel (ESHQ) and some senior managers effort are not captured on the project budget. They are paid by laboratory overhead. P6 is not reflecting the completed project staffing plan.

The project allows historical earned value (EV) changes; the BNL Earned Value Management System (EVMS) process does not allow for this—even for COVID-19, nor does the Project Management Plan (section 3.5) describe this as not allowed or allowed.

3.2 Comments

The CERN shift of the LS3 start date, by an anticipated one year, has no impact on the presented schedule, including planned FDRs for each subsystems.

The project team has a clear picture of the next steps to be completed before the CD-2/3 proposed date. The project team is experienced and has robust tools available for execution. However, significant work remains that could require additional help in the area of project controls personnel. The effort to complete the CD-2/3 preparation and the subsequent SPA process should not be underestimated.

The project indicates that it has agreements with partner institutions, but these may require update.

As planned, the project should update Escalation and Labor Rates to reflect current outlook as soon as possible

The project presented a resource loaded schedule with constraints and with unclear critical paths. For example, the strips WBS has overlapping critical paths (Figure 3-1). After January 2023, a driving critical path is clear.

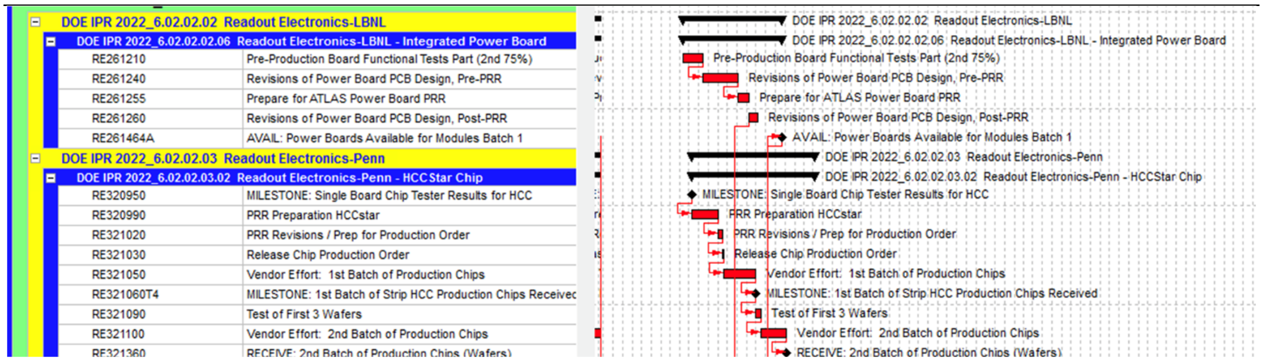


Figure 3-1. Overlapping Critical Paths

Schedule quality tools, e.g., Acumen Fuse (used by project) and/or the Government Accounting Office (GAO) best practice checklist for cost estimating and scheduling may aid in improving product quality before baselining the project.

The presented resource loaded schedule is not showing clear dependencies to CD-2/3 approval date on successor production activities.

The Risk Register includes risks on remaining CD-3A scope, but they are not identified explicitly, making the identification difficult for the Committee.

Estimation uncertainties are calculated using a Monte Carlo analysis. The Monte Carlo approach is correct, but it is complex with respect to what is generally used by other DOE projects.

The WBS dictionary is well documented and identifies the collaboration institutions at Level 3.

Inconsistencies between project documents were found. In particular, the project support personnel in the Project Management Plan (PMP), P6, and BOEs. Checks/updates are suggested (e.g., the PMP states the WBS 6.10 includes project support staff—but P6 does not include it).

The project allows historical earned value COVID-19 changes, which is not in alignment with BNL earned value rules.

The pixel WBS has 58% of its labor hours as uncosted and strips WBS has 41%. Alternative progression techniques should be explored (baseline execution milestones) if standard earned value is not responsive.

3.3 Recommendations

11. Before the CD-2/3 Director's Review, complete all cost and schedule CD-2/3 requirements and address/document earned value process related to historical changes.

12. Before the CD-2/3 Director’s Review, include clear links to successor procurement activities dependent upon the CD-2/3 approval date.

13. Before the CD-2/3 Director’s Review, assure project personnel (costed/uncosted) have formalized agreements.

14. Before the CD-2/3 Director’s Review, continue to scrub BOEs and practice Control Account Manager drill downs.

15. Proceed to the CD-2/3 Director’s Review.

4. PROJECT MANAGEMENT and ENVIRONMENT, SAFETY and HEALTH

4.1 Findings

BNL is the HL-LHC ATLAS host laboratory. The Project Manager is Jonathan Kotcher (BNL), and the Deputy Project Managers are Gustaaf Broojimans (Columbia University) and Harold Evans (Indiana University). The BNL Nuclear and Particle Physics Division provides support to the HL-LHC ATLAS project. Columbia University is the lead institution for the NSF/Major Research Equipment and Facilities Construction (MREFC) award.

The project team is properly staffed with personnel with extensive project management and technical experience to perform the scope of the project.

The project works closely with International HL-LHC ATLAS to understand the support level of international collaborators and its impact on external deliverables.

The DOE guidance for the US HL-LHC ATLAS is $181 million (TPC) with an NSF MREFC award of $75 million. The project presentation focused on the DOE portion without neglecting, where necessary, the connections to the NSF portion.

The project is seeking a combined CD-2/3 approval, with a Director's Review scheduled for June 2022 and a DOE/SC review scheduled for October 2022. The CD-2/3 ESAAB approval, planned for the end of CY 2022, is necessary to maintain schedule of the overall project.

In August 2021, the project had received funding guidance for FY 2022-FY 2026 (Table 4-1).

Table 4-1. Funding Chart

	FY22	FY23	FY24	FY25	FY26
HL ATLAS TPC	$20M	$28M	$15.7M	$17M	$5.8M

A CERN schedule change of LS3 (installation period for the deliverables produced by the project) is anticipated to take place very soon. The schedule change will provide to the project critical float to absorb identified risks.

COVID-19 has impacted the project in the past and is predicted to impact the project in the future, with reduction of work efficiencies expected until end of CY 2022. Past impacts are quantified at $8.0 million, with future impacts estimated at $8.4 million.

The US project is distributed over multiple university and laboratory institutions, totaling more than 30 collaborating institutions. The WBS structure and the Project Organization parallelism is exemplary, down to Level 4. There are eight Level 2 subsystems with deliverables clearly documented in threshold and objective KPPs. The project includes contributions to:

- Pixels (WBS 6.01)
- Strips (WBS 6.02)
- Global Mechanics (WBS 6.03)
- LAr (WBS 6.04)
- Data Handling/DAQ (WBS 6.07)
- Common Costs (WBS 6.09)

Estimate uncertainties and risk contingencies are estimated through a simulation providing a total contingency of approximately 39% on remaining work and a 90% confidence level schedule float larger than the presently available float. However, the project expects that the impending LS3 schedule change will bring in line the 90% confidence level schedule float with the available float.

Project Management presented a post-review high-level timeline to get to the FDR, which is a DOE Order 413.3B pre-requisite to the CD-3 approval. They also described appropriately the road to all Technology Readiness Level (TRL-6) reviews and how they are tied to the FDR.

In discussion on exposure to exchange rate fluctuations, the project explained that aside from the common fund payment, there is little exposure, as most of the funds provided to CERN, for example in WBS 6.2.7 are for procurements in US Dollars (USD), thus the exchange rate cancels out.

BNL ESHQ liaisons are matrixed into US HL-LHC ATLAS. The BNL ESH liaison contacts the liaisons at the institution/vendor sites to review their safety program. The QA liaison works with the technical experts and procurement groups at the institutions to ensure quality of the vendors and the fabrication process of the deliverables. The QA liaison provides information and guidance to the institutional technical teams and their ESH point-of-contacts as needed.

The NSF MREFC is a $75 million project. The funding profile is significantly front-loaded with $27.9 million disbursed by the end of FY 2022 to the project.

4.2 Comments

The US HL-LHC ATLAS team is technically strong and brings significant technical expertise to the execution of the high luminosity upgrade.

The overall US team is led by a strong and experienced Project Office.

The plan prepared by the project with the funding profile provided by DOE/HEP in August 2021 appears executable with a relatively minor pinch point in FY 2024.

The level of uncertainty introduced by the COVID-19 pandemic and the development of future years funding profiles (including considerations on FY 2022 President's Budget Request/Continuing Resolution (PBR/CR) and final budget, FY 2023 PBR, etc.) are unprecedented in the history of SC projects' execution.

While the US ATLAS management was extremely pro-active in addressing the FY 2022 President's Budget Request funding crisis, the uncertainties mentioned above and, especially, the short time-scale between the FY 2023 President's Budget Request publication (March 2022) and the upcoming CD-2/3 Director's Review (June 2022) will present a serious challenge to the project management.

Dramatic changes in the FY 2022 and FY 2023 funding levels with respect to the DOE/HEP August 2021 DOE numbers ($20 million and $28 million respectively) must be avoided, as any dramatic change will require international negotiations with ATLAS and CERN and likely TPC increases due to schedule delays.

Readiness for CD-2/3 is not only dependent on the U.S. project, but needs to be informed by the updated schedule of the international ATLAS project following the CERN modification of LS3. Socialization of new need-by dates need to start in earnest, with finalization of the need-by dates necessary before final preparation for CD-2/3.

The assumption that COVID-19 impacts on activities efficiencies will terminate on December 31, 2022 will have to be revisited on the timescale of summer 2022.

The Materials and Supplies (M&S) impacts due to COVID-19 (approximately 15%) appear to be underestimated at this stage of the planning. This Committee judged that in the near future COVID-19 impacts on M&S will play a more prominent role and a more sophisticated analysis might be necessary. In particular, while individual Level 2s presented Supply Chain Analysis, a collection of the analysis in a common document is recommended.

The 2.5 days durations for a CD-2/3 review, as experienced at this review, appears to be limited to fully address both CD-2 requirements (baseline defense, cost estimate drill-downs, etc.) and CD-3 requirements (readiness for production). The opportunity of a longer duration review (i.e., 3.5 days) should be considered, especially in the present telework environment.

Estimate Uncertainty Contingency (EUC) and risk contingency are understandable and appropriately simulated to demonstrate that the present funding level will allow the project to cover existing risks at approximately 72% confidence level. However, the 72% confidence level appears low when compared to standard practices in DOE/HEP projects.

The time granularity of risk workshops and risks scrubbing to determine required-vs-available contingency is quarterly. The project management team professes confidence in the approach and the Committee is in agreement, although major events or specific moments during the execution of the project might require running a risk workshop on a more frequent basis.

The project explanation about limited exposure to change rates is valid only if the procurement (in US Dollars) and the CERN payment (in Swiss Francs) are close enough in time such that the same exchange rate is used. This is likely a small variation as long as the exchange rate is fairly stable. However, the potential for more scope to be in foreign currency (i.e., bus tapes, where CERN is a viable new vendor for approximately US $1 million) warrants revisiting the answer to the July 2019 CD-3A DOE/SC review recommendation (R10).

The technical team will need to transition to "project mode" immediately to ensure completion and full embracing of the various project regulating documents (Project Execution Plan, PMP, QA Plans, BOEs, etc.). Consistency and cross-checks will require a lot of work.

The status of Memoranda of Understand/Memoranda of Agreement (MOUs/MOAs) between the project and major institutions is uncertain. Such documents are highly recommended to ensure that Laboratory resources are made available throughout the lifetime of the project.

Introduction of proper labor rates in Cobra was described by the project to be time-consuming and introducing minor variations in the obligations making it worthwhile performing only if discrepancies are larger than 5%. The Project Office is invited to assess the amount of work to introduce the appropriate labor rates in Cobra, and possibly delegate the job to junior project control specialists.

Yield assumptions appear adequate.

4.3 Recommendations

16. Before CD-2/3, make sure the Risk Register includes future possible impacts from other COVID-19 events (e.g., Omicron).

17. Before CD-2/3, insure all TRL-6s are executed, in order to conduct the FDR by the advertised timescale of late spring 2022, irrespective of the expected CERN change in LS3 schedule.

18. Before CD-2/3, consider developing appropriate MOUs/MOAs with all the partner laboratories involved in the project.

19. Work with the international ATLAS collaboration to secure an updated ATLAS international schedule as soon as possible, and no later than March 31, 2022

20. Proceed to CD-2/3 Director's Review.

Appendix A Charge Memo

Department of Energy
Office of Science
Washington, DC 20585

11/19/2021

MEMORANDUM FOR KURT FISHER
DIRECTOR
OFFICE OF PROJECT ASSESSMENT

FROM: MICHAEL PROCARIO
DIRECTOR OF FACILITIES
OFFICE OF HIGH ENERGY PHYSICS

Michael P. Procario
Digitally signed by Michael P. Procario
Date: 2021.11.19 10:37:26 -05'00'

SUBJECT: Request OPA conduct an Independent Project Review of the HL-LHC ATLAS Detector Upgrade

I am writing to request that your office conduct an Independent Project Review to assess the status of the High Luminosity Large Hadron Collider (HL-LHC) ATLAS Upgrade project with respect to its preparations toward Critical Decision (CD) 2, Approval of the Performance Baseline, and whether satisfactory progress is being made toward this goal. The review will be held by Zoom on January 25-27, 2022. The most recent Critical Decisions were CD-3A (Approve Long-lead Procurements) approved by Chris Fall 10/16/2019 and CD 1 (Approve Alternative Selection and Cost Range) approved by J. Stephen Binkley 9/21/2018.

In May 2014, the U.S. High Energy Physics program completed its long-term strategic plan through the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel. The P5 plan for Energy Frontier recommended that U.S. actively continue its participation in the LHC program at European Organization for Nuclear Research, and specifically, in the planned HL-LHC upgrades, designating it as the "highest-priority near-term large project". A shutdown is planned to begin in 2024, which will result in the LHC delivering much higher luminosities than the current running conditions in the period from 2026–2035. The new operating conditions require upgrades to the aging ATLAS tracker system, both in the strips and pixel system, the trigger & data acquisition and liquid argon colorimeter read-out electronics.

Your review committee is requested to perform a general assessment of the project's status and the identification of potential issues, as well as addressing the following specific questions:

1. Is progress on development of the proposed technical design adequate to meet the project's milestone for completion by the proposed CD-2/3 timeframe? Is it likely to meet the performance requirements?

2. Is the project making adequate progress on the resource-loaded schedule, risk assessment and contingency estimate to meet the project's milestone for CD-2/3?

3. Does the project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?

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

5. Does the project use the human and technical resources available to it at the participating national labs and universities when they are the most efficient choice? Are qualified vendors being sought out where they are the most cost-effective option?

6. Are the long-lead procurements being managed successfully?

7. Are the ES&H aspects being addressed properly and is the planning sufficient for this stage of the project?

8. Has the project responded satisfactorily to the recommendations from previous independent project reviews?

9. Are there any other significant issues that require management attention?

As Program Manager for the HL-LHC ATLAS Detector Upgrade, Dr. Theodore Lavine will serve as the contact person for the Office of High Energy Physics for this review.

We appreciate your assistance in this matter. As you know, these reviews play an important role in our program. I look forward to receiving your committee's report.

cc: J. Stephen Binkley, SC-2
Harriet Kung, SC-3
Juston Fontaine, SC-4
James Siegrist, SC-35
Theodore. Lavine, SC-35
Kurt Fisher, SC-28
Robert Caradonna, BSO
Jonathan Kotcher, BNL
Dimitri Denisov, BNL

Appendix B Review Committee

DOE/SC pre-CD-2 Review of the
High Luminosity LHC ATLAS Detector (HL-LHC ATLAS) Project at BNL
January 25-27, 2022

Kurt Fisher, DOE/SC/OPA, Chairperson

SC1 Silicon Strips	SC2 Pixel	SC3 Global Mechanics	SC4 Trigger/DAQ
* Steve Nahn, FNAL	* Matthew Jones, Purdue	* Tim Bond, SLAC	* Monica Tecchio, U of Michigan
Anadi Canepa, FNAL	Petra Merkel, FNAL	Stefan Gruenendahl, retired FNAL	Darin Acosta, Rice University

SC5 LAr Calorimeter Electronics	SC6 Cost and Schedule	SC7 Project Management and ES&H
* Terri Shaw, FNAL	* Kathy Bailey, ANL	* Giorgio Apollinari, FNAL
Sergey Los, FNAL	Luisella Lari, FNAL	Kathy McCarthy, ORNL
	Jolie Macier, FNAL	[Steve Nahn, FNAL]

Observers

Mike Procario, DOE/HEP	Mark Coles, NSF
Ted Lavine, DOE/HEP	James Shank, NSF
Abid Patwa, DOE/HEP	
Robert Caradonna, DOE/BHSO	
Cheuk Kwok, DOE/BHSO	

LEGEND

SC Subcommittee
* Chairperson
[ ] Part-time Subcom. Member
Count: 16 (excluding observers)

Appendix C Review Agenda

DOE/SC pre-CD-2 Review of the
High Luminosity LHC ATLAS Detector (HL-LHC ATLAS) Project at BNL
January 25-27, 2022

Agenda

Tuesday, January 25, 2022 (Eastern Standard Time)

10:00 am	Full Committee Executive Session	Fisher
10:45 am	Welcome	Fisher
10:50 am	Project Status and Overview	Kotcher
11:30 am	Technical Status, I&C	Evans
12:00 pm	Baseline Costs & Tracking, COVID BCPs, EVMS	Novakova
12:30 pm	Maturity & Risk, Monte Carlo, COVID Simulations	Brooijmans
1:00 pm	Break	
1:10 pm	Pixels	Grenier
1:40 pm	Strips	Sciolla
2:10 pm	Global Mechanics	Anderssen
2:40 pm	Lunch	
3:15 pm	Liquid Argon	Parsons
3:45 pm	Trigger & Data Acquisition	Majewski
4:15 pm	Break	
4:30 pm	**Subcommittee Breakout Sessions** • Pixels — • Silicon Strips — • Global Mechanics — • LAr — • DAQ — • Management, Cost & Schedule –	
5:00 pm	Full Committee Executive Session	Fisher
6:00 pm	Adjourn	

Wednesday, January 26, 2022

10:00 am	Subcommittee Breakout Sessions	Fisher
12:00 pm	Break	
12:15 pm	Subcommittee Breakout/Executive Sessions	
2:00 pm	Lunch	
3:00 pm	Responses to Questions (Full Committee)	
4:00 pm	Executive Session/Report Writing	Fisher

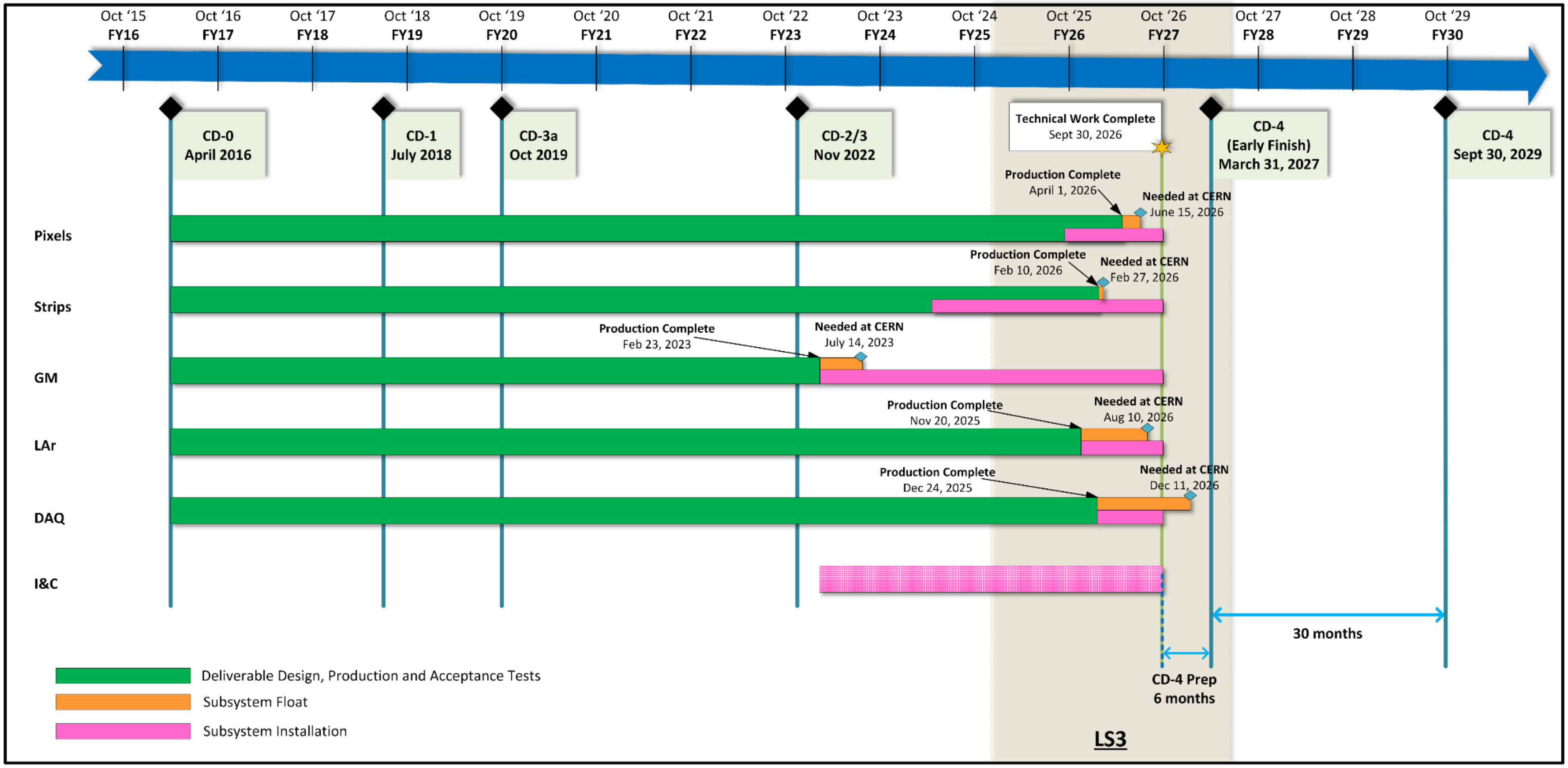
Thursday, January 27, 2022

10:00 am	Executive Session/Report Writing
11:00 am	Closeout Dry Run
2:00 pm	Closeout Presentation
3:00 pm	Adjourn

Appendix D HL-LHC ATLAS Cost Table

WBS	FY 2021 and Prior	FY22	FY23	FY24	FY25	FY26	Grand Total
Deliverables only							
6.01 Pixels	12,077,554	7,171,633	7,192,926	3,388,522	1,595,370	284,251	31,710,255
6.02 Strips	18,045,503	5,980,364	8,470,192	5,916,931	5,904,344	1,231,960	45,545,684
6.03 Global Mechanics	10,422,991	3,509,999	2,118,783	-	-	-	16,051,773
6.04 LAr	2,861,009	998,195	1,116,267	1,072,549	650,668	100,602	6,799,290
6.07 Data Handling/DAQ	4,049,969	2,700,076	3,111,437	1,779,878	1,087,493	74,101	12,802,953
6.09 Common Costs	205,707	1,680,557	532,390	951,390	-	-	3,370,044
6.10 PMO	6,833,535	1,620,754	1,679,969	1,719,539	1,672,531	1,722,675	15,249,004
Total Deliverable Base Cost	**54,496,269**	**23,661,579**	**24,221,963**	**14,828,808**	**10,910,405**	**3,413,589**	**131,532,613**
Total Deliverable CTG	**-**	**23,661,579**	**24,221,963**	**14,828,808**	**10,910,405**	**3,413,589**	**77,036,344**
Contingency, Remaining Covid							
Total MC Cont. (Risk + Maturity)	-	11,086,549	2,927,390	5,788,816	2,680,657	8,608,975	31,092,387
PM Cont.	**-**	**9,701,247**	**9,931,005**	**6,005,667**	**4,255,058**	**1,199,409**	**31,092,387**
Fractional Cont.	-	0.410	0.410	0.405	0.390	0.351	0.404
Remaining COVID cost	-	3,756,831	3,756,831	-	-	861,338	8,375,000
Total Deliverable Cost	**54,496,269**	**37,119,658**	**37,909,799**	**20,834,475**	**15,165,464**	**5,474,335**	**171,000,000**
Funding							
DOE Funds, Guidance (no I&C)	84,515,000	20,000,000	28,000,000	15,700,000	17,000,000	5,785,000	171,000,000
Guidance + Carryover	30,018,731	50,018,731	40,899,073	18,689,274	14,854,799	5,474,335	-
Balance/Carryover	**30,018,731**	**12,899,073**	**2,989,274**	**(2,145,201)**	**(310,665)**	**(0)**	-
TPC: Deliverables + I&C							
I&C Base Cost	-	-	990,809	3,405,212	3,095,285	2,117,073	9,608,380
I&C Cont.	-	-	4,191	374,788	4,715	7,927	391,620
Total I&C Cost	**-**	**-**	**995,000**	**3,780,000**	**3,100,000**	**2,125,000**	**10,000,000**
Total Deliverable Cost	**54,496,269**	**37,119,658**	**37,909,799**	**20,834,475**	**15,165,464**	**5,474,335**	**171,000,000**
Total Project Cost	**54,496,269**	**37,119,658**	**38,904,799**	**24,614,475**	**18,265,464**	**7,599,335**	**181,000,000**

Appendix E HL-LHC ATLAS Schedule Chart



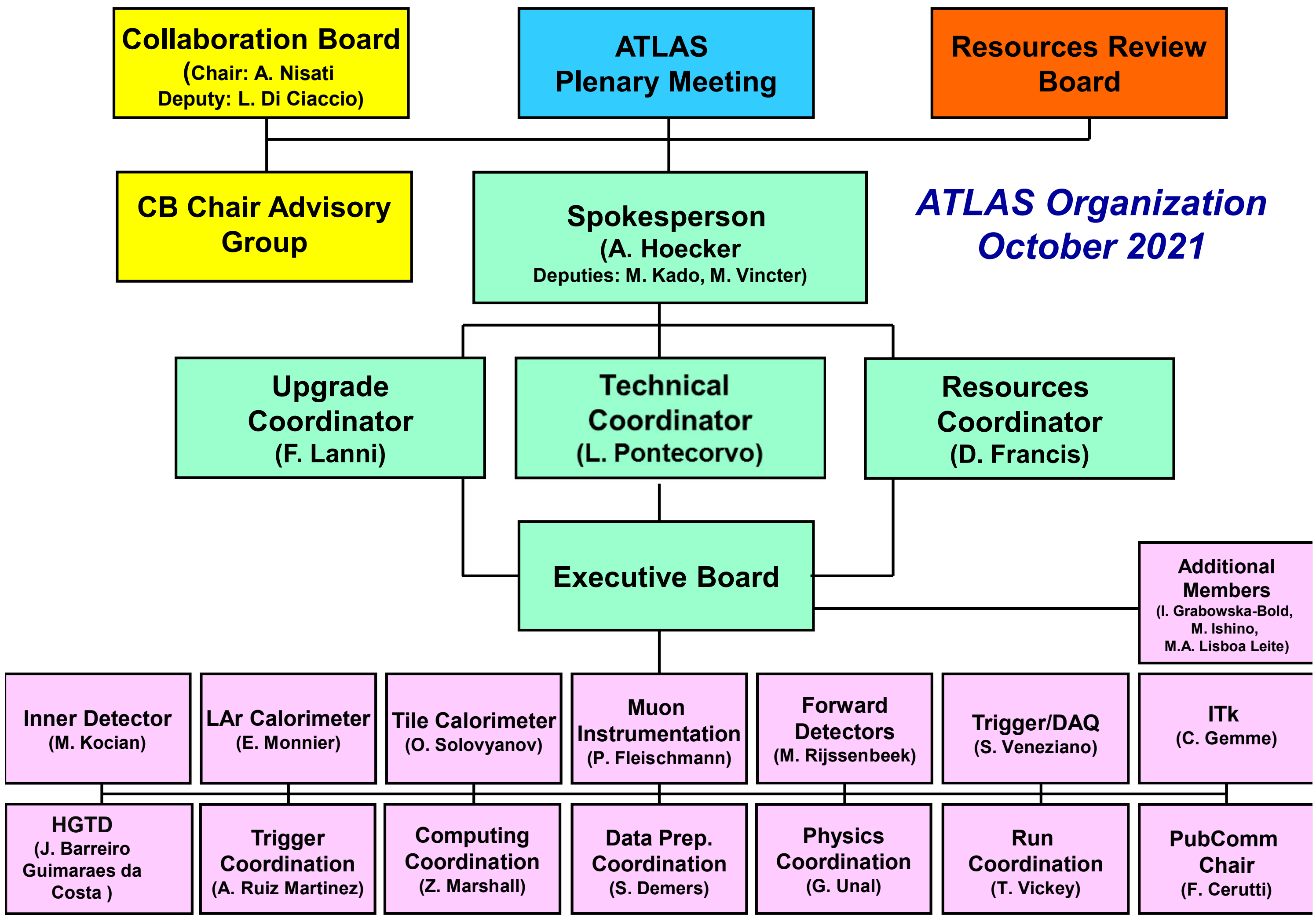
Appendix F HL-LHC ATLAS Funding Table

DOE Profile, Updated Aug 2021

Project Name	BRN	FY 2019 and Prior	FY 20	FY 21	FY 22	FY 23	FY 24	FY 25	FY_26	Total
HL-LHC ATLAS	TEC	27,500	24,500	16,000	20,000	28,000	15,700	17,000	5,785	154,485
HL-LHC ATLAS	OPC	16,515	-	-	-	1,000	3,900	3,050	2,050	26,515
HL-LHC ATLAS	TPC	44,015	24,500	16,000	20,000	29,000	19,600	20,050	7,835	181,000

Profile Difference, Aug 2021 – July 2019

Project Name	BRN	FY 2019 and Prior	FY 20	FY 21	FY 22	FY 23	FY_24	FY_25	FY_26	Total
HL-LHC ATLAS	TEC	-	1,040	(9,040)	(5,910)	10,800	3,300	13,110	5,185	18,485
HL-LHC ATLAS	OPC	-	-	(310)	(990)	(700)	1,400	(250)	850	-
HL-LHC ATLAS	TPC	-	1,040	(9,350)	(6,900)	10,100	4,700	12,860	6,035	18,485


Collaboration Board
(Chair: A. Nisati
Deputy: L. Di Ciaccio)
ATLAS
Plenary Meeting
Resources Review
Board
CB Chair Advisory
Group
Spokesperson
(A. Hoecker
Deputies: M. Kado, M. Vincter)
ATLAS Organization
October 2021
Upgrade
Coordinator
(F. Lanni)
Technical
Coordinator
(L. Pontecorvo)
Resources
Coordinator
(D. Francis)
Executive Board
Additional
Members
(I. Grabowska-Bold,
M. Ishino,
M.A. Lisboa Leite)
Inner Detector
(M. Kocian)
LAr Calorimeter
(E. Monnier)
Tile Calorimeter
(O. Solovyanov)
Muon
Instrumentation
(P. Fleischmann)
Forward
Detectors
(M. Rijssenbeek)
Trigger/DAQ
(S. Veneziano)
ITk
(C. Gemme)
HGTD
(J. Barreiro
Guimaraes da
Costa)
Trigger
Coordination
(A. Ruiz Martinez)
Computing
Coordination
(Z. Marshall)
Data Prep.
Coordination
(S. Demers)
Physics
Coordination
(G. Unal)
Run
Coordination
(T. Vickey)
PubComm
Chair
(F. Cerutti)