Office of Project Assessment
CD-3B/Status Review Report on the

Electron-Ion Collider (EIC) Project

at Brookhaven National Laboratory

January 2025

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Electron-Ion Collider (EIC) project was conducted at the Brookhaven National Laboratory (BNL) on January 7-9, 2025. The review was conducted by the Office of Project Assessment (OPA) in a November 7, 2024 memorandum from Linda Horton, Acting Associate Director of Science for Nuclear Physics (NP). The review was chaired by Kurt W. Fisher, Director, OPA.

The purpose of this review was to assess the overall status of the EIC project as it executes long lead procurements approved at CD-3A, Approve Long Lead Procurement, prepares for CD-2, Approve Performance Baseline, and to determine if it can successfully proceed to CD-3B, Approve Long Lead Procurement. In general, the project team has made excellent progress since the November 2023 DOE/SC review and there is an experienced team in place. A new Technical Director was hired January 2024 and has already made a positive impact on the project. The project has strong support from the BNL and Thomas Jefferson National Accelerator Facility (TJNAF) Directors. Some significant changes were recently introduced including the relocation of the Rapid Cycling Synchrotron (RCS) outside the Relativistic Heavy Ion Collider (RHIC) tunnel. The project team developed and proposed a new tailored approach implementing subprojects to maintain momentum. While the Committee noted some delays in the execution of CD-3A procurements, they judged that the project team has identified previous issues through a lesson learned review. The Committee supports the project proceeding with CD-3B and recommended a mini-review in six months in support of the recent developments.

Injector

The relocation of the RCS effectively solves and mitigates several technical feasibility risks, while also simplifying the RHIC tunnel layout and easing congested areas at various interaction region (IR) locations. The Committee endorsed this choice.

The requirements for the direct current (DC) electron gun for the low energy cooling (LEC) system are significantly beyond the state-of-the-art-performance presently demonstrated by the DC gun and high quantum efficiency (QE) semiconductor cathode technologies. A significant R&D effort is necessary to demonstrate the required performance.

The most pressing item appears to be the down-select of linac type, followed by incorporation and investigation of all relevant collective effects (e.g., space charge field longitudinal space charge, coherent synchrotron radiation, wakes) in the gun-to-RCS line and dependencies to facilities infrastructure.

Collider

There have been significant changes and progress towards a buildable accelerator design, including removing the strong hadron cooling (SHC) and adding the LEC for a flat beam, moving the electron RCS outside of the RHIC tunnel, and hadron injection and bypass plans. These are very positive developments towards the revised project baseline.

Given the complexity of the project, it is important to maintain a version-controlled major parameters lists to document the machine design configuration meeting user expectations and project constraints and to guide the establishment of system requirements (as documented by System Requirements Documents, SRD) and interfaces (as documented by Interface Control Documents, ICD).

Many recent projects including the Linac Coherent Light Source II (LCLS-II), LCLS-II High Energy (LCLS-II-HE; SLAC National Accelerator Laboratory or SLAC, Thomas Jefferson National Accelerator Facility or TJNAF, Fermi National Accelerator Laboratory or FNAL, and Michigan State University or MSU), and Facility for Rare Isotope Beams (FRIB; MSU) benefited tremendously from a wide vendor base from both domestic and international industrial providers. EIC may consider expanding the vendor base/countries similarly leveraging experience from partner laboratories.

The efforts towards value-based selection between building IR magnets in-house at BNL versus partnership with other National Laboratories is commendable.

The Committee strongly supported the inclusion of LEC in the project scope, which will be essential for the establishment of flat beams.

Accelerator Support Systems

The project should start developing system prototypes early to meet project needs, including defining and collecting requirements for project-wide, high-level applications (e.g., inventory tracking, cable management, progress tracking from design to operations).

Some physics requirements for high performance systems (e.g., bunch-by-bunch beam diagnostics, including the Electron Storage Ring or ESR) have not been received by technical groups. The Committee encouraged the project team to clarify the physics requirements, as these may influence the technical system design.

RF Systems

The issues with the single-cell 591 MHz cavity and cryomodule impacted the system's delivery and testing for a year. If additional issues surface during the test, there is very little time for the design changes to be incorporated into the project's overall design on the current schedule (end of FY 2029).

The crab cavities are systems even more complex than single-cell 591 MHz cavities. The project team should expedite the development and design of the crab cavities and the first article of the 197 MHz cryomodule and proceed with the procurement as soon as possible. Similarly, the in kind contribution (IKC) of 394 MHz crab cavities should be formalized as soon as possible.

Cryogenic Systems

Current staffing plans show significant spikes in resources. Resource levelling should be completed on many of the L2 and L3s.

While technical workarounds exist to interface the new supervisory control and data acquisition (SCADA) cryogenics control system with EPICS (Experimental Physics and Industrial Control System), the Committee recommended further evaluation of its long-term sustainability, including maintenance costs (e.g., in-house expertise, operator burden in the micrometer controlled regulator), troubleshooting, and cross-system correlations, among other factors, leveraging experiences from other DOE facilities like the Spallation Neutron Source (SNS), FRIB, LCLS/LCLS-II.

Detector

Three CD-3B items (scintillating fibers, lead tungstate crystals, and steel plates/machining/coating/welding) are continuations of procurements authorized by CD-3A. All of these are long lead time items and the Committee agreed that they need to be procured as soon as practical to mitigate schedule risks.

Two CD-3B items (flux return steel/detector support structures for endcap calorimeters and solenoid high current power supply) are related to the detector solenoid magnet. Both are also long lead time items and the Committee agreed that they need to be procured as soon as practical to mitigate schedule risks.

The Committee commended the project and the Electron-Proton/Ion Collider (ePIC) collaboration on the progress made towards final designs for all the detector subsystems.

It is important that an agreement be reached with CERN to allow ePIC ASIC designers access to monolithic active pixel sensors (MAPS) design files so that they can be modified for the outer tracker layer.

Infrastructure

The infrastructure team was commended for their progress since the November 2023 review and for the very well thought out and articulated presentations. The Committee was pleased to learn about the project receiving the New York State grant ($100 million) in February 2024.

The currently proposed plan with four discrete work packages (vs. original plan with one overall construction management/general contractor (CM/GC) work package) introduces complexity and risks associated with the dependencies and interactions between the work packages. This plan will require greater coordination and oversight by BNL.

The new electron injector complex southeast of RHIC needs to have the design, cost, and schedule maturity increased as expeditiously as possible to ensure technical performance, cost and schedule meet overall project expectations.

The infrastructure team will likely need to add staff to lead the design development of the electron injector complex.

Environmental, Safety, Health, and Quality (ESH&Q)

With the new injector plan, revisit required documents such as National Environmental Policy Act (NEPA), and the Hazard Analysis Report for the changes. This may also apply to other project documents, such as the Assumptions Document.

At the next review, the project should clarify how the IKC partners participate in the change control process and how the ePIC collaboration's technical change control process interfaces with the project's change control process.

The tools in place for quality assurance/quality control have not all been fully exercised and will need further assessment. For example, what is the process to resolve a non-conformance report (NCR) in a timely manner?

Cost and Schedule

Project controls systems and processes are established and have been demonstrated via the CD-3A scope. Project controls are well integrated with the project and work seamlessly between the Laboratories.

The start of CD-3A earned value tracking has very little data, which is normal for the start of these types of procurement activities. The majority of the planned value will not be visible until after contract award and vendors begin performing work. The project should consider including a metric of obligations vs. plan as part of routine reporting. The addition of pre-award milestone tracking metrics to monthly project reporting would provide visibility into the procurement cycle, providing data to support/validate the process changes in response to the CD-3A procurement lessons learned.

While the project recently completed lessons learned of the CD-3A procurements, there was no evidence of the efficacy of the corrective actions implemented.

Proposed subproject strategy implementation needs to be carefully planned to meet the target dates for CD-2/3 for the first subproject.

Remaining open recommendations are appropriate but should continue to be worked to closure prior to CD-2/3 for the first subproject.

Project Management

The Committee judged that the project team has made excellent progress since the November 2023 review and that there is an experienced team in place. A new Technical Director was recently hired and has already made a positive impact on the project. The project has strong support from the BNL and TJNAF Directors.

The project presented a subproject strategy that would maintain project momentum and progress made to date and to mitigate schedule risks that could be imposed by potential funding constraints. However, the strategy decision was recently made and there was insufficient time for the project to develop the details necessary for the Committee to assess the validity of the scope, cost, and schedule of the proposed subprojects along with the benefits cited.

The pivot to subprojects and preparing to baseline Subproject 1 will take considerable planning and preparation by the project team and must be done in parallel to socializing with stakeholders and aligning support.

The development of an overall EIC project delivery plan is encouraged with roles and responsibilities defined in a way to avoid disconnects caused by the subproject strategy.

The recent approach to establish an Interim EIC Portfolio Coordinator is already providing value in making the entire EIC enterprise visible and the need to understand interfaces and interdependencies. The project team was encouraged to utilize a systems engineering approach to the extent appropriate to manage requirements and interfaces across the entire EIC portfolio.

BNL must work more expeditiously to inform DOE on the scope and cost of the EIC portfolio. This is essential to inform budgetary planning at BNL and DOE/NP and to inform essential decisions needed to facilitate project planning and execution.

Key Recommendations

- Perform a comparative analysis between super- and normal-conducting linac options for the electron injector and down-select to the preferred baseline. Complete by end of the scheduled April 2025 review.
- Allocate resources and prioritize the electron injection system redesign to allow development of cost and schedule estimates including civil construction to the level of a preliminary design review. Complete in time to support the project's CD-2/3C review (presently scheduled for second quarter FY 2026).
- Allocate funds and resources necessary to complete the R&D required for the low-energy cooler electron gun. Develop plan within six months, to complete research by the CD-2/3C review.
- Establish version-controlled major parameters lists for the accelerator complex to document the machine design configuration meeting user expectations and project constraints and to guide the establishment of system requirements and interfaces; report at the next DOE/SC review.
- Define scope, deliverables, and Key Performance Parameters for each of the subprojects; report at the next DOE/SC review.
- Retain the options open (including space) for future implementation of beam cooling at the collision energies. Report progress at the next DOE/SC review.
- Onboard construction manager advisor (CMa) for constructability reviews and cost estimating prior to completion of the design.
- Prior to the next DOE review, revisit the infrastructure team staffing plan considering the recently added scope of the electron injector complex (RCS and electron injector) to ensure adequate staffing in parallel with execution of initial infrastructure scope.

- Advance the conceptual design of the conventional construction of the electron injector complex and present at the next DOE/SC review.
- Mature the conceptual cost and schedule of the conventional construction of the electron injector complex, by the next DOE/SC review.
- ICDs must be developed for all systems prior to baselining the scope and present the progress at the next DOE/SC review.
- Augment the project reporting to increase visibility of the procurement life-cycle, to include the pre-award progress and obligation of contract award, within the next three months.
- Develop a detailed plan to achieve CD-2/3 for the first subproject, with documented decision points, within the next three months.
- In advance of the next DOE/SC review, document the scope of EIC project and gain alignment with DOE/NP on mission need achievement.
- Develop details for the subproject strategy and work with DOE/NP and the Federal Project Director to conduct a focused review in six months.
- Proceed to CD-3B.

CONTENTS

Executive Summary i
1. Introduction 1
2. Technical Systems Evaluations 4
    2.1 Injectors 4
    2.2 Collider 7
    2.3 Global Accelerator Systems 11
    2.4 Detector 17
3. Infrastructure 20
4. Cost and Schedule 24
5. Project Management and Environment, Safety and Health 28

Appendices

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

1. INTRODUCTION

The Office of Nuclear Physics (NP) in the U.S. Department of Energy (DOE) Office of Science (SC) is supporting the implementation of the Electron-Ion Collider (EIC) to be built at Brookhaven National Laboratory (BNL) in partnership with Thomas Jefferson National Accelerator Facility (TJNAF). The EIC's performance parameters include a high beam polarization of 70 percent from both electrons and light ions; capability to accommodate ion beams from deuterons to the heaviest stable nuclei; variable center of mass energies from 20 to 140 GeV; high collision luminosity from 10^{-33} to 10^{-34}; one detector, a schematic of which appears in Figure 1, and one interaction region (IR) at project completion; and capacity to accommodate a second IR.

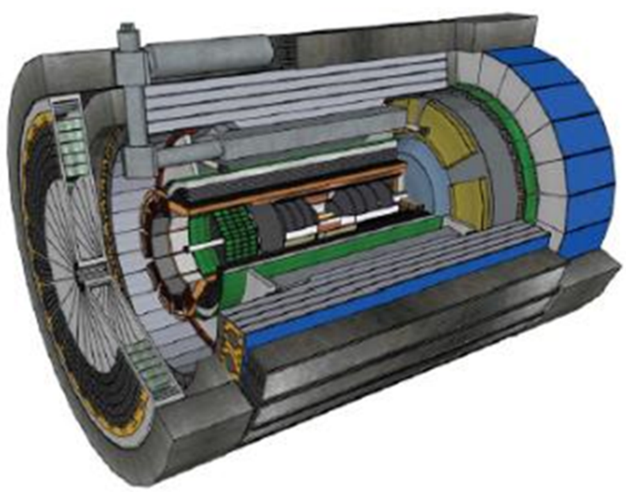


Figure 1: Project Detector, "ePIC"

The planned scope, as described in the work breakdown structure (WBS) dictionary and partially shown in Figure 2, will include a new electron injection system and storage ring that takes advantage of existing infrastructure by modifying the currently operating Relativistic Heavy Ion Collider (RHIC) at BNL. The electron system as described in the WBS will include a highly polarized room temperature photo-electron gun and a 400 MeV linear accelerator to be installed in an existing available straight section of the RHIC tunnel. It will include a transfer line that brings the electrons into the storage ring at an energy of 5 to 18 GeV that will be installed in the existing 2.4-mile circular RHIC tunnel. The project presented another concept for electron injection involving constructing a new ring outside the RHIC tunnel as shown on the right in Figure 2.

Modifications to the existing hadron system will include the injection, transfer line, and storage ring to increase beam energy to 275 GeV. An analysis of alternatives conducted prior to Critical Decision (CD) 1, Approve Alternate Selection and Cost Range, selected strong hadron cooling (SHC) as the preferred alternative to reduce and maintain the hadron beam emittance to the level needed to operate with the anticipated luminosity of 10^{-33} to 10^{-34}. The IR will have superconducting magnets, crab-cavities, and spin rotators to provide longitudinally polarized beams in collisions, and one detector.

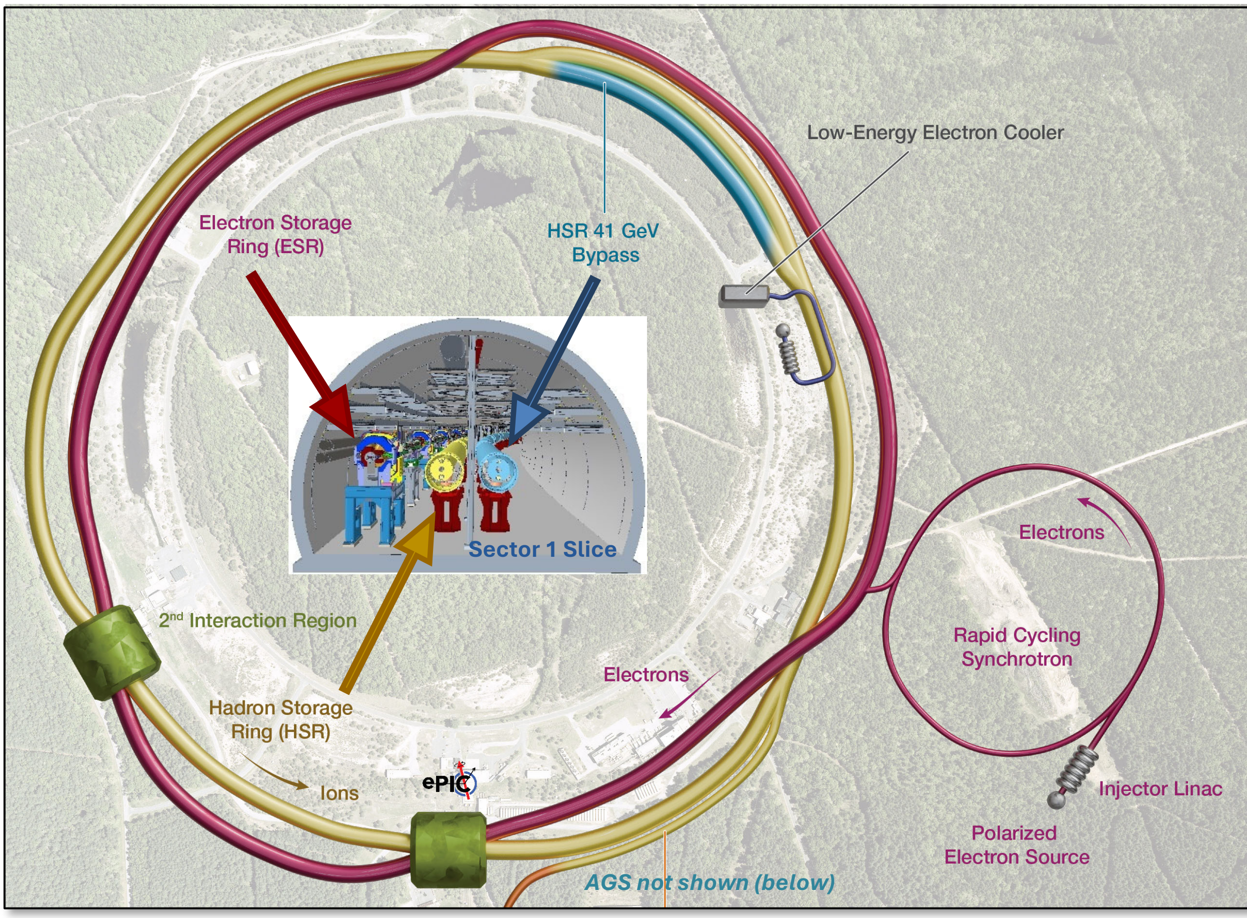


Figure 2 EIC Concept, with Injector Linac Outside of the RHIC Ring

An enhanced 2K liquid helium cryogenic plant will provide superconducting RF cavities with enhanced water-cooling capacity while new cooling towers and chillers will stabilize the environment in the existing tunnel. Civil construction will also include electrical systems, service buildings, and access roads.

The detector, planned to have a 9.5-meter length, capable of detection over an 80-meter extended region, will have far-forward and far-backward detectors, and a 1.7 T magnet with the same geometry as the BaBAR magnet. Detector capabilities will include tracking, particle identification, electromagnetic calorimetry, and hadronic calorimetry functionality in all directions.

Jointly commissioned by DOE/SC and the National Science Foundation (NSF), a July 2018 National Academy of Sciences (NAS) consensus study report found the scientific case for the construction of an EIC in the U.S. compelling. The 2023 Nuclear Science Advisory Committee Long Range Plan deemed EIC as the community's highest priority for facility construction. An EIC will enable scientists to investigate and answer questions about the fundamental building blocks of nuclei and how quarks and gluons, the particles inside neutrons and protons, interact dynamically via the strong force to generate the fundamental properties of neutrons and protons, such as mass and spin. Comparing the existing and proposed accelerator facilities around the world, the NAS Committee concluded that an EIC with high energy and luminosity, as well as highly polarized electron and ion beams, would be unique and in a position to greatly advance our understanding of visible matter.

The project attained CD-0, Approve Mission Need, on December 19, 2019; the Director of SC selected BNL as the location for the EIC on January 9, 2020; and BNL and TJNAF signed a partnership agreement to work jointly in the implementation of the EIC on May 7, 2020. On June 29, 2021, the acting Under Secretary for Science and Energy approved CD-1 with a cost range of $1.7-2.8 billion. Approval of a long-lead procurement, CD-3A, supporting accelerator, detector, and infrastructure scope, with a cost of $90 million, occurred March 28, 2024.

In a November 7, 2024, memorandum (Appendix A), Dr. Linda L. Horton, Acting Associate Director of the Office of Science for Nuclear Physics, requested that Kurt Fisher, Director, Office of Project Assessment (OPA), SC, conduct a review of the EIC project, which was conducted at BNL on January 7-9, 2025. The purpose of the review was to assess the status of the EIC project's technical definition, schedule, cost, management, environment, safety and health (ESH), and quality assurance as it executes long lead procurements approved at CD-3A and prepares for CD-2, Approve Performance Baseline, and to determine if it can successfully request a second long lead critical decision, CD-3B.

Kurt Fisher chaired the Review Committee (Appendix B). Committee members were chosen based on their technical or project management expertise, and experience with building large scientific research facilities, as well as their independence from the project. The Chairperson organized the Committee into seven subcommittees, each assigned to evaluate a particular aspect of the project corresponding to members' areas of expertise, including: 1) electron injection; 2) the collider comprised of hadron storage ring and ESR, with emphasis on SHC; 3) accelerator systems covering superconducting radio frequency cavities, cryogenics, and controls; 4) the detector; 5) infrastructure; 6) cost and schedule; and 7) project management, environment, safety and health, and quality assurance. The Brookhaven and Thomas Jefferson Site Offices (BHSO and TJSO, respectively) and SC headquarters staff jointly developed the agenda (Appendix C). Committee members based their assessments on relevant statutes, regulations, DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets, other Department directives and standards, OPA guidance, and lessons learned from similar recent projects.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Injectors

2.1.1 Findings

The EIC project proposed its intent to organize itself into multiple subprojects that will be executed in a parallel fashion with staggered starting times. As presented at the review, the first subproject to start includes the electron and hadron storage rings, followed by detectors and IR as a second project. The third subproject encompasses the electron injector and associated infrastructure. The fourth (and, as presented, last) subproject will commence after a proposed multi-year operation of the facility for early science, and includes the scope required to bring the EIC project to its ultimate performance. The Committee noted that at this time, the number and coverage of subprojects has not been finalized.

The electron injector system has undergone multiple design evolutions attempting to find a viable solution for an in-RHIC tunnel Rapid Cycling Synchrotron (RCS), including increasing the injection energy from 400 MeV to 3 GeV. The project has very recently decided to move the RCS outside the RHIC tunnel, and to build it in a new dedicated enclosure outside the ring. The present electron injector concept includes a superconducting linac, intended to enable direct injection of 7-nC bunches into the RCS. A previous design of the electron injector system included a normal-conducting S-band linac, also intended to deliver 7-nC bunches to the RCS. A low-energy beam accumulator ring (BAR) will be required to deliver 28-nC bunches to the RCS regardless of linac technology selected.

The polarized electron beam source, demonstrated at Stony Brook University, appears to meet all operational needs of the EIC project.

The strong hadron cooling (SHC) system was recently removed from the project scope and replaced by a low-energy electron cooling (LEC) scheme. Detailed simulations also indicate that even for the case of an ideally operating SHC, the gain in terms of average luminosity would be limited to a factor of 2 with respect to the case of LEC. The electron source for the LEC is identified as a 600-kV DC photoelectron gun generating at least 70 mA average current; the voltage requirement may be somewhat relaxed pending results of ongoing modeling work.

The new RCS location results in a reduction in overall magnet count, and a reduction in the numbers of types of magnets required, versus the in-tunnel design. New RCS magnet designs are presently being modified from those developed for the in-tunnel RCS design. Magnet field quality and tolerancing studies are starting now. The project will determine whether ramped (dynamic) testing is required (e.g., to characterize the effects of eddy currents).

As with the magnets, the vacuum, diagnostic and magnet power supply systems for the new RCS concept are very similar to those developed for the in-tunnel RCS, but with generally reduced component counts. The vacuum system design is very mature. The diagnostic plan, while preliminary in many respects, appears thorough and well thought out in terms of placement and measurement type. The magnet power supply design approach includes features to improve safety and maintainability.

The magnet power supplies will require upgrades to achieve the ultimate goal of 18-GeV injection into the EIC electron storage ring (ESR). Current design efforts include a modular approach to allow extension, rather than replacement, of initially installed supplies where feasible.

Wakefield and impedance evaluations are ongoing. Present results do not indicate concern for 7-nC operation in the RCS and appear promising for 28-nC. Other identified subsystem challenges for 28-nC operation include the possibility of beam position monitor (BPM) button heating, arcing, and signal levels at the higher charge.

2.1.2 Comments

The project team is effectively executing the work, and technical issues are being appropriately and proactively addressed. The Committee was impressed with the progress to date, given the short amount of time since the changes to the electron injection system.

The R&D and design efforts are yielding sufficiently advanced designs and mitigating technical risk, especially given the recent changes in RCS location and design. The results of the polarized gun testing, in particular, are of note, and the project team is commended.

Given that the electron injector complex (identified by the project at this review as Subproject 3 or SP3) is nominally slated to reach CD-2/3 at second quarter FY 2028, the project is making adequate progress towards developing the performance baseline. The main performance requirements have not changed, but the change in RCS location must drive a reevaluation of subsystem performance requirements, scope, etc.

There were no recommendations from the November 2023 DOE/SC reviews for this area. However, other reviews recommended reevaluation of the RCS location; the project responded with a series of workshops and mini-reviews, culminating with the decision to move the RCS out of the RHIC tunnel and into its own enclosure.

The relocation of the RCS effectively solves and mitigates several technical feasibility risks, while also simplifying the RHIC tunnel layout and easing congested areas at various locations, including the IRs. The Committee endorsed this choice.

The design of the new RCS and related linac injector is at a preliminary phase, and detailed and complete scope and cost estimates still need to be developed. Doing so requires down selecting between the normal-conducting and superconducting options for the electron linac. The subproject for the electron injector, SP3, must also be tightly coupled to studies for SP4 (upgrade to full performance) to avoid inadvertently limiting machine performance.

The choice between super- and normal-conducting linacs is not simply financial, as it involves partner lab participation, and also impacts eventual operating and maintenance costs, operational cycles, and ultimate achievable performance.

The parallel execution of multiple subprojects may result in competition for resources. In particular, the schedule of the electron injector subproject, which design is presently at an early stage and will, if executed as presented at the review, be the last to complete prior to early science, can be potentially impacted. Project management should ensure coordination between the subprojects, manage conflicts over resource availability and carefully monitor interface points and area of joint or overlapped responsibility.

The significant amount of time for early science (approximately five years) between the end of construction and start of final upgrades raises concerns regarding magnet power supply upgradeability, in terms of both vendor survival and component availability.

The requirements for the DC electron gun for the LEC are beyond the current state-of-the-art performance presently demonstrated by DC gun and high-QE (quantum efficiency) semiconductor cathode technology. A significant R&D effort is necessary to demonstrate the required performance. The project has at least two options to consider: pursuit of a new gun being developed at Stony Brook University, and potential improvements to the existing LEReC gun. The project is encouraged to consider investigating both options in parallel until the required performance has been demonstrated.

The most pressing issue appears to the Committee to be the down select of linac type, followed by incorporation and investigation of all relevant collective effects (e.g., space charge, longitudinal microbunching, coherent synchrotron radiation, wakefields, etc.) in the gun-to-RCS portion of the electron injector, and dependencies to facilities infrastructure.

From the information presented, it seems that the level of definition of the normal-conducting linac for the RCS injector is not at the same level of the superconducting linac option. A similar level of development for both options is required to ensure a fair and meaningful comparison. Given the project intends to make a decision in April 2025, there is not much time to perform the studies.

Incorporating the BAR into the initial construction of the electron injector complex, rather than during the final upgrades, would provide risk reduction for linac performance and infrastructure design.

Very little information was given regarding how the electron injector complex will interact with downstream systems (e.g., beam-abort and feedback systems in the ESR).

While there is no injector system scope in CD-3B, this Committee sees no reason not proceed to CD-3B approval, based on the information presented.

2.1.3 Recommendations

1. Perform a comparative analysis between superconducting and normal-conducting linac options for the electron injector and down select to the preferred baseline. Complete by end of the scheduled April 2025 review.

2. Allocate resources and prioritize the electron injection system redesign to allow development of cost and schedule estimates including civil construction to the level of a Preliminary Design Review. Complete in time to support the project CD-2/3C review (presently scheduled for second quarter FY 2026).

3. Allocate funds and resources necessary to complete the R&D required for the low-energy cooler electron gun. Develop plan within six months, to complete research by the project CD-2/3C review.

4. Evaluate which components of the RCS, especially the magnet power supply systems, are subject to upgrade risk (e.g., vendor survival, component availability) given the time between the end of electron injector construction (currently identified as SP3), and the start of final performance upgrades (identified as SP4). Given those risks, determine which components, if any, should be developed at the performance levels for 18-GeV, 28-nC operation within SP3. Complete by second quarter FY 2028 (nominally the scheduled CD-2/3 for SP3).

5. Evaluate cost and schedule impact, and potential for risk mitigation, of including the BAR in initial electron injector construction. Complete by the project CD-2/3C review.

2.2 Collider

2.2.1 Findings

The list of approved $90.0 million CD-3A long lead procurement contains five accelerator systems items all associated with the hadron machine and subsystems totaling $31.1 million:

1. HSR vacuum beam screen profile material (WBS 6.05.04.01),
2. Cryo BPM buttons and cables (WBS 6.05.05.01),
3. Superconducting strand for collared and direct wire magnets (WBS 6.06.02.07),
4. 591 MHz 1-cell cryomodule first article components (WBS 6.08.03.02), and
5. Cryogenic 2 K satellite plant for IR 10 (WBS 6.09.02.02).

The list of long lead procurement requests ($52.6 million including 35% contingency) in preparation towards readiness for proceeding to CD-3B contains five accelerator systems items all associated with the ESR totaling $27.1 million plus 35% contingency:

1. ESR dipole magnets (WBS 6.04.02.01),
2. APS sextupole refurbishment (WBS 6.04.02.02),
3. ESR magnet measurement bench (WBS 6.04.02.04),
4. ESR quadrupole refurbishment (WBS 6.04.03.01), and
5. ESR APS magnet measurement stand (WBS 6.04.03.01).

The project team identified two major scope contingency opportunities: SHC and the hadron 41 GeV by-pass. The project team proposed removing SHC from the project scope and adding LEC to the project scope. SHC was the CD-1 preferred alternative.
Other major changes incurred are:

- Reuse the entire Yellow RHIC ring, delay the 41-GeV bypass (a Blue RHIC arc,
- Implement a new room temperature HSR injection line,
- Move RCS out of the collider tunnel, and
- Delay the 28 nC/bunch and the 18 GeV capability implementation.

The project team proposed four subprojects:

- SP1: collider,
- SP2: detector + IR,
- SP3: electron injector, and
- SP4: other in-scope work including adding RF to increase electron charge from 7 nC/bunch to 28 nC/bunch and energy from 10 to 18 GeV. Maturity of accelerator sub-systems in the order from the most to the least is: 1) HSR, 2) ESR, 3) IR magnets; and 4) Electron Injector.

The critical accelerator technology areas identified are:

1. Hadron beam cooling,
2. Beam polarization,
3. Crab cavities, and
4. IR magnets.

There are ten identified high accelerator risks, three in the process of being mitigated by the proposed design changes (RCS integration in the tunnel; 400-MeV linac does not meet requirements; SHC performance falls short of expectations), seven remaining (RCS impedance too high; ESR impedance too high; HSR impedance too high; direct-wound superconducting magnet failure; collared superconducting magnet does not meet requirements; 197-MHz crab cavity does not meet requirements, and unforeseen severe events during commissioning.

Several major proposed changes to the accelerator design have not yet been reviewed by the EIC Machine Advisory Committee (MAC) and the Director's Review Committee.

Accelerator Development and R&D

A flat beam with transverse emittance ratio exceeding a factor of ten was experimentally demonstrated at injection energy under LEC.

The measured secondary electron yield (SEY) of the prototype vacuum screen sample coated at BNL reached design requirement of SEY < 1.02.

A luminosity model has been established including most relevant mechanisms that may cause emittance growth and beam loss. The highest average luminosity that may be achieved without and with SHC are about 2.0×10^{33} $cm^{-2}s^{-1}$ and 4.1×10^{33} $cm^{-2}s^{-1}$, respectively and in the presence of LEC.
Conceptual design of electron-cooler based LEC is in progress assuming electron-hadron interaction length of 170 m, using space previously reserved for SHC. Conceptual design of

electron-cooler based high energy cooling (HEC) is under discussion. Upgrades would be needed if the existing RHIC stochastic cooling system is used for EIC.

Electron Storage Ring

Used magnets on girders (retired from the Advanced Photon Source (APS) at Argonne National Laboratory (ANL)) were transported to BNL and TJNAF. Dynamic aperture calculations were conducted with conservatively anticipated magnetic errors including doubling the quadrupole and sextupole magnet errors measured at ANL 30 years ago.

Hadron Ring

Injecting hadrons with a new room temperature injection line instead of a blue ring arc, eliminating the 41 GeV bypass, and moving the electron RCS outside of RHIC tunnel significantly simplifies the physical beamline layout in the collider tunnel.

Results from the luminosity model were presented to the EIC MAC. The Committee stated "Given the risk, costs, and integration challenges, SHC appears to provide insufficient overall benefit. Consider deferring SHC until Phase 2 or beyond."

Interaction Regions and Detector

Moving electron RCS outside of the collider tunnel simplifies the design of the IR and the detectors.

Beam-beam studies continue. Ion beam quality in the vertical plane is found to be more vulnerable under diffusion and noise and is sensitive to the working point choice.

Special BPMs are included in IR for crabbing angle measurements.

2.2.2 Comments

There have been significant changes and progress towards a buildable accelerator design, including removing the SHC and adding the LEC for a flat beam, moving the electron RCS outside of the RHIC tunnel, and hadron injection and bypass plans. These are very positive developments towards the revised project baseline.

The project needs to provide a realistic estimate for the time needed to finalize the technical scope of the changes proposed. Accelerator design basic choices should not change/evolve for at least six months before CD-2.

Given the complexity of the project, it is important to maintain version-controlled major parameters lists to document the machine design configuration meeting user expectations and project constraints and to guide the establishment of system requirements (as documented by System Requirements Documents, SRD) and interfaces (as documented by Interface Control Documents, ICD).

The project decided for subprojects vs. delaying CD-2 for the overall project. While it is positive to advance parts of the project that are more ready and to put equipment in the tunnel, there are negatives to consider: interfaces, dependencies, added management layers, complexity of Key Performance Parameters (KPP) and budgets. The decision should be revisited and validated again once the overall accelerator scope is better defined.

The first three of the four planned subprojects are not in sequential order of beam establishment. It is important to define appropriate KPPs in order to verify subproject completion. The scope, deliverables, and KPPs of each subproject are yet to be defined.

There are still significant remaining accelerator high risks (seven) as listed in Section 2.2.1 Findings including IR magnets, crab cavities, and ring impedances, even assuming the full mitigation of injector complex related risks.

The planned scope contingency of SHC, which was the CD-1 preferred alternative, and the 41 GeV bypass, compromises achieving the ultimate performance parameters of the project. The impact on user needs and facility life-cycle cost should be evaluated and documented.

Many recent projects including Linac Coherent Light Source II (LCLS-II), LCLS-II High Energy (LCLS-II-HE; SLAC National Accelerator Laboratory or SLAC, Thomas Jefferson National Accelerator Facility or TJNAF, Fermi National Accelerator Laboratory or FNAL, and Michigan State University or MSU) benefited tremendously from a wide vendor base from both domestic and international industrial providers. EIC may consider expanding the vendor base/countries similarly leveraging experience from partner laboratories.

The efforts towards value-based selection between building IR magnets in house at BNL versus partnership with other National Laboratories is commendable.

The Committee strongly supported inclusion of LEC in the project scope. LEC will be essential for the establishment of flat beams.

HEC is being considered, and space should be reserved for cooling at high energy. The project team should discuss with NP how to support the development efforts on HEC. Given the success of the existing stochastic cooling system in RHIC, the EIC team should also evaluate the benefit and value of upgrading the system for EIC ion runs at storage energy.

The Committee had no overall concerns about the accelerator scope for CD-3B.

The Committee strongly supported the request for additional beam study time in 2025, since it is the last time that RHIC can be run. Moving electron RCS outside of the RHIC tunnel significantly simplifies the IR detector design and shielding.

The direct wind magnets are significantly pushing the technical envelope and prototyping will be critical.

It is encouraging and commendable that a flat beam in RHIC with transverse emittance ratio exceeding a factor of ten has been experimentally demonstrated at injection energy under LEC.

Also commendable are the efforts in vacuum developments including the measured secondary electron yield (SEY) of the prototype vacuum screen sample coated at BNL that reached design requirement of SEY < 1.02.

Artificial intelligence and machine learning (AI/ML) are likely to play important roles in EIC operations. Requirements on beam diagnostics and other related systems should be considered from the early design stage.

2.2.3 Recommendations

6. Establish version-controlled major parameters lists for the accelerator complex to document the machine design configuration meeting user expectations and project constraints and to guide the establishment of system requirements and interfaces; report at the next DOE/SC review.

7. Define scope, deliverables, and KPPs for each of the proposed subprojects; report at the next DOE/SC review.

8. Retain the options (including space) for future implementation of beam cooling at the collision energies. Report progress at the next DOE/SC review.

9. Evaluate benefits of upgrading the existing stochastic cooling system for ion operations. Report progress at the next DOE/SC review.

2.3 Global Accelerator Systems

2.3.1 Findings

The controls team has made good progress identifying dedicated resources since the November 2023 DOE/SC review, with three controls experts now dedicated to the EIC. Controls resources are expected ramp-up the from 2.72 in FY 2024 to 14.75 in FY 2025, reaching a peak of 33.99 in FY 2026, giving a large jump from FY 2024 to FY 2025 (approximately 12 full-time equivalents or FTEs) and even larger from FY 2025 to FY 2026 (approximately 20 FTEs). In addition to developing a targeted plan for contract labor to limit growth and variability, consideration has been given to absorbing resources from CAD. Resource levelling has not yet been completed.

The Controls WBS has been stabilized since the November 2023 review, with minor changes to the “Controls - Hardware Procurement” WBS. Previously comprehensive, it is now limited to “Controls” items that are not associated with other WBS areas within Controls. The Controls team is also actively working on the Level 4 WBS “Controls – Detector” (potentially 6.07.02.12), with approval expected in FY 2025. This particular Level 4 WBS is likely to be associated with the future SP2.

The Controls Common Hardware Platform offers a standardized solution for a wide range of high-performance data acquisition and control applications. As of July 2024, the project team successfully completed the Preliminary Design Review (PDR), achieving 30% maturity. The second prototype revision is expected to be delivered in January 2025. The EIC Accelerator

Controls development environment has been set up, with core infrastructure in place for basic demonstrations, and work is underway to expand capabilities for performance metrics and final design tasks.

The Controls team identified a path to CD-2, with Preliminary Design Reviews planned to achieve 60% design maturity. These include Software, Networking, and Computing Infrastructure in third quarter FY2025; Common Platform Remote Interface in third quarter FY2025; and Safety Systems in fourth quarter FY2025, among others.

The Controls team must handle various software and organizational interfaces. The control system will be a combination of EPICS (Experimental Physics and Industrial Control System) for on-project systems and legacy ActiveX Data Objects (ADO) for inherited off-project systems. Safety systems ownership is shared between multiple groups: controls, cryogenic systems, radiation safety, etc. Plans for network and computing have matured for the updated fiber plant, with shared understanding between different stakeholders including Controls, Infrastructure, the Architect/Engineer, Information Technology Division, and so on.

The team is working on a plan to make controls AI ready—the plan is to be presented at a later date.

A tiered and hierarchical star structure for EIC timing data link, as well as machine protection system (MPS) has been adopted to distribute information to all EIC locations. The central node currently planned in 1005S will likely move to an alternate existing building due to space and accessibility concerns, together with the timing and MPS hub.

Significant work is underway to complete a bottoms-up estimate for installation work using similar methods to what was previously completed for the removal bottoms-up. As with controls, resource levelling for installation has not yet been completed.

Removal of RHIC hardware is off project. Many of the same people are working on the removal, as well as the installation. Installation risks are well understood and developed at this stage of the project. Removal of the blue ring and the RCS has significantly reduced space congestion and provided relief to the installation schedule.

RF Systems (WBS 6.08)

The EIC RF Systems provides the superconducting and normal-conducting RF systems for RCS, ESR, HSR, crab systems, and SHC ERL. These include cavities and cryomodules, high power RF systems, and RF controls. The project is in the pre-CD-2 phase, and many RF subsystems are still in the design process.

The project baseline preparation is ongoing, and additional scope to the RF systems will be added to support the Electron Injection System, LEC, and staging of ESR RF system installation to provide the required power and voltage. In total, 64% of the 822 requirement documents are complete. The RF system internal interfaces are documented, tracked, and approved via Systems

Engineering. Interfaces are developing as RF Systems and other EIC areas mature for the project baseline. Currently, there are 19 active risks related to the RF systems. Seven risks were retired. Two high risks on 591 MHz First Article (FA) and crab cavity FA remain.

The FA 591 MHz 1-cell cavity cryomodule procurements have been delayed due to unresolved technical issues not identified at FDR in the First Article design. These issues are related to wakefield budget, beamline device heating, cavity multipacting, and cavity tuning. The new design of the 591 MHz FA cryomodule has been developed, and the RF design review took place in December 2024.

The High Order of Magnitude (HOM) absorbers have been tested with the traveling wave at an equivalent power density on the absorber. Cold testing of the 197 MHz DVC cavity is scheduled for September 2025. The project includes eight 197 MHz and six 394 MHz crab cavities. The design of the cavities and cryomodules is complete. The 197 MHz crab cavity prototype fabrication started. The crab cavities require low-level radio frequency (LLRF) that is beyond state-of-the-art. The LLRF PDR is complete.

The normal-conducting RF preliminary design report is complete for 18 HSR cavities. The additional scope is expected from LEReC and possibly from EIS if the linac is based on normal-conducting structures.

The high-power systems include high-power RF (HPRF) amplifiers and the high-power transmission components, which connect the amplifiers to the RF cavities. New high-power amplifiers are assumed to be solid state amplifiers (SSAs), which will be built to specification using commercial vendors. The ESR cavities require 2 x 400 kW CW SSAs at 591 MHz with the total of 14 MW of installed RF power for 17 cavities. The project is procuring 2 x 200kW and 2 x 400kW 591 MHz SSAs for ESR cryomodule testing and design verification.

The LLRF controls is an RF system-specific platform based on an EIC Common Platform, a field programmable gate array (FPGA)-based controller developed and delivered from the Controls WBS. The LLRF group developed an EIC RF cavity simulator to enable the early development of LLRF. Other developments include a One-Turn Delay Feed Back (OTFB) and Feed Forward systems to reduce transient beam loading and ultra-low phase noise LLRF for crab cavities. The requirements for crab cavity LLRF are under development, meanwhile, the RF LLRF Controls team is making progress to prototype specific LLRF system to meet the needs. The project team reported concern about whether current available technology can meet the physics requirements.

A Project Change Request (PCR) for modifying the WBS 6.08 structure is being developed and will be implemented after the CD-3B review.

Cryogenic Systems (WBS 6.09)

Project plan includes a distributed cryogenic system with the already existing central plant providing 4 K cryogens and two satellite plants with cold compressors to distribute 2 K helium to the cryomodules. The previously planned 2 o’clock satellite plant will be deleted with removal of SHC from the project. The 4 K central plant has sufficient overhead to accommodate the expected loads and the 2 K systems are being designed for 25% margin. The 4 K system is planned to use as much of the existing RHIC system as possible; however, this will require new valve-boxes, detector cryo-interfaces, and special segments for 2 K distribution tie-ins.

The decision was made to use hard pipe connections vs the original plan of using U-tubes along with double valve isolation for the cryomodules.

Resource demand shows a significant ramp-up—the project recognizes the need to resource level the schedule.

The cryogenics controls have adopted a new supervisory control and data acquisition (SCADA) based solution and are transitioning from the existing system. The new SCADA system now controls all components of the cryogenics system, including the cryo plant, distribution, cryomodule, SRF, magnets, and more.

2.3.2 Comments

The project team is effectively executing work, including good progress on the long-lead procurements authorized by CD-3A. As such, the project is well positioned to complete CD-3A scope within the established schedule and cost baseline. Technical issues have been addressed appropriately and proactively. The Committee noted that there have been some delays, which do not yet affect the critical path. The project has satisfactorily addressed recommendations from previous DOE/SC reviews, with the response to some recommendations still underway. In particular, the Committee emphasizes the importance of continued work on the recent RF physics design review held in December 2024. The Committee judged that the project is ready for CD-3B approval.

Accelerator Support Systems (WBS 6.07)

Given that major resource spending occurs in FY 2026-FY 2028, and the project team is still working on a plan to make controls AI ready, there is concern that AI requirements may arrive late. Accordingly, there is risk to implementing the controls systems prior to developing a detailed plan for AI readiness, including data acquisition, online training, and online deployment of models. In addition, reliance on legacy ADO controls for off project systems may make it difficult to achieve high-rate, synchronous data acquisition for those systems.

Virtual controls system and virtual accelerators have proven their value in recent DOE projects. Integrating new AI-enabled digital twins and model interfacing into the controls infrastructure could eventually improve commissioning and reduce maintenance. Leveraging recent DOE experience early could accelerate the development of other systems, such as high-level and physics applications. Establishing an infrastructure to support high-speed data acquisition from accelerator hardware will enable future development and integration of emerging technologies like AI/ML, Digital Twin, and model interfacing.

The project should start developing system prototypes early to meet various needs, including defining and collecting requirements for project-wide, high-level applications (e.g., inventory tracking, cable management, progress tracking from design to operations).

The Committee observed various challenges handling interfaces between different parts of the project. The Committee suggested defining and documenting clear interfaces and responsibilities between the Controls team and technical systems (accelerator and detector). Careful management of WBS is needed to avoid duplication or gaps in scope, particularly for Earned Value Management System (EVMS) analysis, progress tracking, and system readiness analysis. The Committee suggested clarifying ownership of technical subsystem controls, from hardware to high-level tools, and to develop a sustainable plan for the entire project lifecycle, focusing on minimizing maintenance and supporting cross-training among engineers. Some physics requirements for high performance systems (e.g., bunch-by-bunch beam diagnostics, including the ESR) have not been received by technical groups. The Committee encouraged the EIC team to clarify the physics requirements, as these may influence the technical system design. Continued improvement of the controls development environment (software and hardware) will support early developments of other systems, such as high-level applications.

The current Controls WBS dictionary, especially at Level 4, has overlaps that need to be clarified to avoid confusion and better define scope. Also, if the "Controls – Detector" WBS (likely 6.07.02.12) is linked to SP2, the project team should understand its impact on the readiness of detector control system to support the EIC project's scientific mission. The Committee suggested developing document requirements for a standardized controls naming system, covering hardware, rack, and EPICS processing variables.

The project's construction schedule and budget need to be satisfied while aligning controls systems with cybersecurity requirements. The Committee suggested prioritizing needs to minimize future maintenance and operational risks.

The Gantt chart and labor profile presented during the breakout sessions highlighted challenges in clearly conveying progress, emphasizing the need for better alignment with the technical subsystems. The Committee suggested developing a plan to manage the projected FTE increase from FY 2024 to FY 2026, especially for EPICS system development training, addressing the need for less experienced resources.

The timing system receives inputs from the LLRF of each ring, which are sent to the master timing node to synchronize the beam and data acquisition. This approach, demonstrated at RIHC, will be applied to the EIC. Given the differences between electron and hadron beams, the Committee urged the project team to take another look and evaluate its feasibility. The Committee suggested that the project team identify and prioritize R&D tasks to develop system requirements for the global MPS and timing system and other critical systems, as well as conducting a full analysis to understand the risks and impacts of moving critical systems (like timing and MPS) from building 1005S to an alternate location, including identifying all systems to be moved and documenting findings.

The installation team should prioritize continuing development of the bottom-up installation plan to fully understand the scope and costs associated, especially with the proposed new electron injector.

RF Systems (WBS 6.08)

The issues with the single-cell 591 MHz cavity and cryomodule impacted the system's delivery and testing for a year. If additional issues surface during the test, there is very little time for the design changes to be incorporated into the project's overall design on the current schedule (end of FY 2029).

To avoid additional possible issues similar to those experienced with the first article 591 MHz cryomodule, the Committee suggested that the project team develop an updated beam physics requirements for the frequency-dependent impedance budget for all RF cavities in all EIC accelerators. If new data appears, the requirements document should be updated accordingly.

The crab cavities are systems even more complex than single-cell 591 MHz cavities. The project team should expedite the development and design of the crab cavities and the first article of the 197 MHz cryomodule and proceed with the procurement as soon as possible. Looking at the current status of the 197 MHz crab cavity and knowing that tuning the cavity to frequency is very sensitive to the accuracy of the components, the cold test scheduled for September 2025 seems tight. Similarly, the in kind contribution (IKC) of 394 MHz crab cavities should be formalized as soon as possible.

The project RF team should be commended for adequately handling the development, design, and procurement of NCRF and high-power RF systems.

Cryogenic Systems (WBS 6.09)

Current staffing plans show significant spikes in resources. Resource levelling should be completed on many of the Level 3s.

While technical workarounds exist to interface the new SCADA cryogenics control system with EPICS, the Committee recommended further evaluation of its long-term sustainability, including maintenance costs (e.g., in-house expertise, operator burden in the MCR), troubleshooting, and cross-system correlations, among other factors, leveraging experiences from other DOE facilities like SNS, FRIB, LCLS/LCLS-II.

Given that the team is already developing a cryogenics controls plan prior to developing a plan to make controls AI ready, there is concern that changes needed for AI applications (data acquisition or control) may arrive too late.

2.3.3 Recommendations

10. Deliver a realistic resource demand plan for global accelerator systems (6.07-6.09) no later than the next DOE/SC review.

11. Develop a centralized project plan to enable AI for global accelerator systems (6.07-6.09), including data acquisition and control. Report plan at the next DOE/SC review.

12. Initiate development of a virtual controls system environment by next DOE/SC review while capturing experiences from recent DOE projects.

13. Report plan on critical controls systems including timing, MPS, Personal Protection Systems (PPS), including prioritization of development by next DOE/SC review.

14. Expedite development to achieve 60% and 90% maturity on technical system controls, better positioning the team for success, particularly in establishing the performance baseline prior to CD-2/3.

15. Proceed with the integrated design of the single-cell 591 MHz FA to prepare for the cavity string Final Design Review (FDR) in May 2025. Follow up with all recommendations of the RF physics design review held in December 2024 and ensure that the December reviewers are invited for the cavity string FDR.

2.4 Detector

2.4.1 Findings

CD-3A includes roughly $10 million for the design and fabrication of the detector superconducting solenoid magnet. The expectation of the ePIC collaboration is that the design and fabrication of the solenoid will be an IKC from INFN (Italy) and CEA-Saclay (France).

The reference design for the solenoid magnet and request for design/build bid package have been completed. If the IKC does not materialize by summer 2025, the bid package will be released by TJNAF. If an agreement formalizing the IKC is reached, the project will realize an associated (opportunity) risk of approximately $10 million.

CD-3A includes money to pay for the fabrication of superconducting wire for the solenoid. A request for proposals has been released and a bid from the preferred vendor is expected soon (the vendor asked for and was granted more time to reply than specified in the request for proposals).

CD-3A includes money to pay for the fabrication of steel elements of the detector forward hadronic calorimeter. This steel is part of the magnetic flux return for the solenoid. A request for proposals has been drafted, but not yet approved by the site office.

CD-3A includes money to pay for approximately half of the silicon photomultipliers (SiPMs) needed for the Hadron Endcap calorimeter. This order (with options for future orders of the same type of SiPM) was placed in November 2024.

CD-3A includes money to pay for approximately two-thirds of the lead tungstate crystals needed for the backward electromagnetic calorimeter. A request for quote has been issued and a quote received from the preferred vendor. This contract will also be structured as an initial purchase order with options for subsequent orders. A purchase order has not yet been placed.

CD-3A includes money to pay for scintillating fiber for the detector barrel and forward endcap electromagnetic calorimeters. In both cases the contracts are being structured as a purchase order for one batch of fibers with the option (expected to be exercised one year at a time) to purchase three additional batches. The contract for the first batch of fibers for the forward endcap calorimeter was awarded in December 2024. A request for proposals for the first batch of detector barrel fibers has been released, but a quote has not yet been received.

CD-3B includes money to pay for the balance of the lead tungstate crystals needed for the backward electromagnetic calorimeter. A group of ePIC collaborators has submitted an NSF MSRI (Mid-Scale Research Infrastructure) proposal that will pay for all of the crystals of the backward electromagnetic calorimeter if it is awarded.

CD-3B includes money to pay for the second phase of scintillating fiber orders needed for the detector barrel and forward electromagnetic calorimeters.

CD-3B includes money to pay for the second phase of fabrication of steel elements for the detector forward hadronic calorimeter.

CD-3B includes money to pay for fabrication of half the endcap flux return steel structures (which support the endcap calorimeters). This contract will be structured as a purchase order for approximately half of the endcap flux return with the option to purchase the balance.

CD-3B includes money to pay for the design and fabrication of the high current power supply required for the detector solenoid magnet.

CD-3B includes money to pay for 5500 Versatile Link Plus Transceivers (VTRx+) and 1500 low power Gigabit Transceivers (lpGBT). These will be used for the MAPS trackers, the dRICH, and other subsystems. This order includes all of the VTRx+ modules and lpGBT ASICs required for ePIC (including spares).

The current fiscal year is expected to be the last year that there will be R&D money for ePIC detector development.

Some of the developments funded so far by R&D money will transition to Project Engineering and Design (PED) funding. One notable example is the final steps of development of the FCFD (Fermilab Constant Fraction Discriminator) ASIC (application specific independent circuit).

A number of technical reviews of detector R&D were held in 2023 and 2024. As a result, the collaboration changed two baseline technologies (mRICH → pfRICH; SciGlass EMcal → Imaging EMCal).

One-track studies based on PYTHIA simulations indicate that ePIC can achieve the pT resolution requirements. This is achieved by combining the silicon tracker with a number of other subsystems (CyMBaL, microRWELL-BOT, microRWELL-ECT).

The decision to locate the RCS in a separate tunnel has allowed a reduction in the amount of flux return steel for the detector solenoid magnet, significantly reducing the total weight of the ePIC detector. Nonetheless the ePIC detector will still weigh approximately 20% more than the STAR detector and it is not known whether or not this will exceed the load-carrying capability of the IR-6 floor. BNL plans to hire an architecture and engineering firm to assess this situation and if necessary to modify the floor. This work will be done off project.

Off project upgrades to the assembly building are also planned. These include extending the building to allow access to the tunnel while the detector is rolled out into the assembly building. Recently the alternative of building a new access way to sector 5 of the tunnel has been proposed.

The question of how the beam pipe will be baked out without damaging the vertex detector (whose temperature cannot exceed ~30C) is an unresolved issue. A solution has been envisioned and will be tested with mockups in 2025.

2.4.2 Comments

Three CD-3B items (scintillating fibers, lead tungstate crystals, and steel plates/machining/coating/welding) are continuations of procurements authorized by CD-3A. All of these are long lead time items and the Committee agreed that they need to be procured as soon as practical to mitigate schedule risks.

Two CD-3B items (flux return steel/detector support structures for endcap calorimeters and solenoid high current power supply) are related to the detector solenoid magnet. Both are also long lead time items and the Committee agreed that they need to be procured as soon as practical to mitigate schedule risks.

The last CD-3B item is the purchase of VTRx modules and lpGBT ASICs for use with the MAPS trackers, the dRICH, and other subsystems. It is exceedingly important that this purchase be authorized now so that it can be done in conjunction with the CERN purchase of VTRx and lpGBT for the HL-LHC experiments.

The Committee commended the project and the ePIC collaboration on the progress made towards final designs for all of the detector subsystems.

It is important that an agreement be reached with CERN to allow ePIC ASIC designers access to MAPS design files so that they can be modified for the outer tracker layer.

Simulations with one track show that the required tracking resolution can be met. Full ep studies have been initiated, but no eA study is yet planned. The Committee encouraged the project to work closely with the ePIC collaboration to ensure that eA studies be done to confirm that the detector will meet performance expectations.

Tunnel access near IP1006 will be required for detector solenoid magnet commissioning and also for the installation of IR components such as final focus magnets. Currently, these components would be brought in through the 1006 assembly hall. However, the presence of the detector in the assembly hall would conflict and impede tunnel related activities. Two off project solutions have been envisioned:

1. Extend the assembly hall to allow IR access. Unfortunately, the hall cannot be extended far enough to allow work on the detector while the IR is being accessed without extending the coverage of the overhead crane, which would be very expensive.
2. Build a new access point to the tunnel in sector 5 so that large components and equipment can be brought into the tunnel without impeding detector related activities in the assembly hall. The Committee judged that option 2 is favored by a wide margin because it would eliminate conflicts between detector assembly and commissioning and IR installation.

2.4.3 Recommendation

16. Encourage project management to strongly support the off-project addition of a new tunnel access to sector 5.

3. INFRASTRUCTURE

3.1 Findings

The Infrastructure group is responsible for all phases on design, construction, and commissioning of the conventional facilities including the buildings, sitework, building services and electrical power and cooling utilities required to support the operation of EIC. The group's scope is comprised of four components:

- Infrastructure Management at Engineering (WBS 6.11.01)
- Civil Construction (WBS 6.11.02)
- Electrical Power Systems (WBS 6.11.03)
- Cooling Systems (WBS 6.11.04)

The 60% detailed design was submitted on December 13, 2024 (on schedule). Design work completion (100% Conformed Set) is planned for June 2025. The next value engineering workshop will be held in January 2025. There is no infrastructure scope in the CD-3B scope package. Infrastructure would be part of SP1 and SP3 if the decision to re-plan EIC using subprojects moves forward.

The New York State (NYS) Empire State Development (ESD) grant of $100 million for EIC buildings was received in February 2024. Unit substation scope (15 units), part of the CD-3A approval, was solicited to NYS Minority/Women Owned Business Enterprises (MWBEs), as required by the NYS ESD grant, and two qualified bids were received within the project's cost estimate. The unit substation contract (CD-3A scope) was awarded December 13, 2024, for 15 units, at $11,215,430, and an 88 week delivery.

Infrastructure scope paid for with NYS ESD grant funds is not subject to critical decision approval, so any work funded with ESD funds may proceed prior to CD-3, however, the team plans to follow the DOE Order 413.3B process with the ESD scope to integrate with the overall project plan. The NYS grant has MWBE subcontracting requirements that are compulsory.

The Code of Record document (Doc # EIC-ORG-RSI-026) was approved on November 25, 2024.

The plan to utilize a construction manager/general engineer (CM/GC) is no longer being considered. The infrastructure group hired a new Infrastructure Construction Manager in September 2024. The Construction Manager Advisor (CMa) contract has not yet been awarded. Infrastructure scope is being broken down into four work packages (WP):

- WP#1: Site Preparation
- WP#2: Building Construction
- WP#3: Civil/Low Voltage Electrical/Cooling
- WP#4: High Voltage Electrical

The acquisition strategy for infrastructure scope is being reconsidered given the decision not to proceed with a comprehensive CM/GC contract. New EIC buildings are currently planned to comply with the 2016 Guiding Principles for Federal Leadership in Sustainable Buildings but are not currently planned to pursue LEED Gold certification. The Infrastructure team provided "RFI 93 - High Performance Sustainable" outlining their assessment of sustainability requirements and their conclusion not to pursue LEED or a waiver from the Project Management Executive (PME). The project decided to develop a new external electron injector complex southeast of RHIC. The details of the design, cost and schedule are under development. The Infrastructure team now has to refocus efforts to guide the conceptual, preliminary and final design of the conventional construction of the electron injector complex. The project is currently planning on submitting NYS grant funding applied to the project, to the Site Office for review and approval.

3.2 Comments

The Infrastructure team is commended for its progress since the November 2023 review and for the very well thought out and articulated presentations. The Committee was pleased to learn about the project receiving the NYS grant ($100 million) in February 2024. Congratulations on getting the CD-3A unit substation scope awarded under budget. Detailed design work has progressed well with adequate controls in place to ensure design quality thus far.

The infrastructure project management team should be commended for thorough tracking of progress in detailed monthly reports, ensuring EVMS metrics are accurate and up-to-date. The project's use of an Infrastructure Construction Advisory Committee (ICAC) is a best practice and provides valuable perspective. Formal partnering with construction contractors is a best practice identified at other laboratories. The Committee suggested the Infrastructure team consider utilizing formal partnering in its construction contracts.

Reconcile code/standards cited in the architect/engineer 60% Design and the CMa Scope of Work to ensure they are consistent with the approved EIC Code of Record document. Multiple inconsistencies were noted.

The 60% design package is not developed to support the new subproject/work package strategy and re-tooling the design going into 90% may result in delays to the design schedule. The currently proposed plan with four discrete work packages (vs. original plan with one overall CM/GC work package) introduces complexity and risks associated with the dependencies and interactions between the work packages. This plan will require greater coordination and oversight by BNL. Work is required by the Infrastructure team to align the four infrastructure work packages with the tentative subproject approach. It would be prudent to align work packages with subprojects to avoid cross-subproject work. The infrastructure group is well positioned to support a subproject tailoring strategy given the current level of design maturity. However, re-tooling the design and planning procurement packages to support subprojects could introduce risk and complexity which may result in unexpected coordination issues during construction (change orders).

The new electron injector complex southeast of RHIC needs to have the design, cost and schedule maturity increased as expeditiously as possible to ensure technical performance, cost and schedule meet overall project expectations. The Infrastructure team will likely need to add staff to lead the design development of the electron injector complex.

The ICDs should be prepared soon to ensure proper integration between WBS and systems. Utilizing pre-engineering buildings that house sensitive equipment (for example the laser for the electron injector) will require appropriate design characteristics (for example temperature and ground stability, and cleanliness).

The project team states that LEED certification does not apply to buildings constructed as part of EIC, but DOE Order 413.3B requires pursuit of LEED Gold certification, absent an approved waiver from the PME. The project team's assessment of sustainability requirements applicable to EIC infrastructure projects, as outlined in the "RFI 93 - High Performance Sustainable" document provided by the project team, appeared to be out of date. It references the 2016 Guiding Principles for Federal Leadership in Sustainable Buildings, which were significantly revised in 2020. It also references EO 13834, which was revoked in January 2021.

The project team communicated that the EIC Infrastructure scope does not have scope contingency and is currently designed with a small margin of floor space to ensure adequate space to house equipment and support Operations and Management (O&M). Should the infrastructure scope bids come in high, the project may be forced to move scope to a later subproject, rather than cut infrastructure scope, as there is not identified deductive alternate scope.

3.3 Recommendations

17. Onboard CMa for constructability reviews and cost estimating prior to completion of the design.

18. Investigate pursuing a LEED waiver from the PME if it is confirmed that the DOE Order 413.3B requirement to pursue LEED Gold certification does apply to the EIC Infrastructure Buildings, prior to baselining the project (or first subproject).

19. Prior to the next DOE/SC review, revisit the infrastructure team staffing plan considering the recently added scope of the electron injector complex (RCS and electron injector) to ensure adequate staffing in parallel with execution of initial infrastructure scope.

20. Advance the conceptual design of the conventional construction of the electron injector complex and present at the next DOE/SC review.

21. Mature the conceptual cost and schedule of the conventional construction of the electron injector complex, by the next DOE/SC review.

22. ICDs must be developed for all systems prior to baselining the scope and present the progress at the next DOE/SC review.

4. COST and SCHEDULE

4.1 Findings

PROJECT STATUS as of 11/30/2024		
Project Type	Line Item	
CD-1	Planned: Q3 FY21	Actual: 6/29/2021
CD-3A	Planned: Q2 FY24	Actual: 3/28/2024
CD-3B	Planned: Q2 FY25	Actual:
CD-2/3C	Planned: Q2 FY26	Actual:
CD-3	Planned: Q2 FY27	Actual:
CD-4	Planned: Q1 FY36	Actual:
TPC Percent Complete	Planned: N/A %	Actual: N/A %
TPC Cost to Date	$254.0 M	
TPC Committed to Date	$23.3 M	
TPC	$1.7–2.8 B	
TEC	$1.6–2.6 B	
OPC	$0.1–0.2 B	
Contingency Cost (w/Mgmt Reserve)	$627 M	_____% to go
Contingency Schedule on CD-4	24 months	_____%
CPI Cumulative	N/A	
SPI Cumulative	N/A	

CD-3A

CD-3A was approved on March 28, 2024, with a pre-baseline value of $66.7 million plus 35% contingency. The CD-3A baseline was set May 1, 2024. The baseline value of the CD-3A scope was $69.749 million. The planned value of the CD-3A scope in November 2024 was $74.079 million.

Four project change requests (PCRs) have been approved to date:

- Set baseline ($3.092 million increase from pre-baseline)
- Milestone coding and logic cleanup (net $0)
- Scope addition, Magnet Beam Screens (add $4.376 million)
- Contract award, superconducting strands (subtract $47,000)
- There are no pending PCRs

Management reserve (MR) and contingency usage includes:

- Established at baseline: MR = $0, Contingency = $20.238 million
- November 2024 (21.4 % usage): MR = $47,000, Contingency = $15.862 million

Work authorization documents (WADs) have been issued for the totality of the CD-3A scope ($74.079 million).

The WBS dictionary was updated to reflect the scope added through PCRs.

The project plans to obligate ~$67 million of CD-3A scope in FY 2025.

Through the end of November 2024, only $21,000 of CD-3A work was scheduled, with $2,000 work performed, at an actual cost of $400 (Cost and Schedule Performance Indices (CPI/SPI) = 5.6 and 0.1, respectively).

There are 17 planned procurements in CD-3A—four have been awarded for approximately $14 million. Of the 13 remaining, 11 have forecast dates beyond the baseline dates. The project conducted a lessons learned exercise to evaluate the root cause of the delays, these lessons learned are to be applied to CD-3B procurements.

A design issue was noted with the 591 MHz 1-cell cryomodule, which has resulted in a schedule impact.

Unit substations were awarded under budget.

CD-3B

CD-3B is necessary because it reduces technical risk, as well as market risk due to limited vendors.

The planned value of CD-3B scope is $52.598 million. This includes $13.637 million (35%) contingency. Most CD-3B funds will be obligated in FY 2026 and FY 2027.

There are 17 risks in the Risk Register for CD-3B—six have already been retired, the remaining 11 are active and are characterized as threats. Of these 11, the pre-mitigation rankings are one high, nine moderate, and one low. However, the post-mitigation rankings are three moderate and eight low.

There are 26 prior actions in the log that originated from the Cost and Schedule Subcommittees of prior reviews. There are currently five actions with a status of “Open” or “In Progress”, which have been open for one to four years. The ages range from one to four years, with the oldest from January 2021 and the latest from November 2023.

All FDRs are complete for the CD-3B scope.

The project plans to issue new WADs for all CD-3B scope, including the scope that is a continuation of current CD-3A scope.

Control Account Manager (CAM) interviews were conducted on three control accounts: WBS 6.4.2 - G. Mahler; WBS 6.4.3 - S. Philip; and WBS 6.10.5 - A. Bazilevsky.

CD-2

The projects CD-1 Total Project Cost (TPC) range at approval (June 2021) was $1.7-2.8 billion.

The project's current point estimate is $2.963 billion, which includes 35% cost contingency on work to go and 10% on level of effort (LOE) activities. There are 24 months of schedule contingency to CD-4. The project point estimate does not include off project scope of Approximately $250 million.

The project identified approximately $330 million (minimum) scope contingency.

RHIC operations are still planned to conclude at the end of CY 2025.

A major design change has been proposed in the accelerator area.

The project intends to subdivide its scope into four subprojects. SP1 through SP3 are anticipated to deliver early science, while SP4 will bring the EIC to its full capability. Initial planning of SP1 is currently estimated at ~$800 million (with contingency).

Preliminary KPPs are being renegotiated between the program and the project to align with low end of Mission Need Statement.

There are 188 active risks in the project Risk Register, of which 11 are opportunities. There have been 102 risks retired to date.

New DOE funding in any given fiscal year is not expected to exceed $150 million. A decision associated with subproject planning is expected within six months.

The project controls team is currently comprised of ten BNL and four TJNAF staff.

4.2 Comments

Project controls systems and processes are established and have been demonstrated via the CD-3A scope. Project controls are well integrated with the project and work seamlessly between the laboratories.

The start of CD-3A earned value tracking has very little data, which is normal for the start of these types of procurement activities. The majority of the planned value will not be visible until after contract award and vendors begin performing work. The project should consider including a metric of obligations vs. plan as part of routine reporting. The addition of pre-award milestone tracking metrics to monthly project reporting would provide visibility into the procurement cycle, providing data to support/validate the process changes in response to the CD-3A procurement lessons learned.

While the project recently completed lessons learned on CD-3A procurements, there was no evidence of the efficacy of the corrective actions implemented.

CD-3B threats seem appropriate for this phase of the project, addressing procurement and performance related concerns, as well as external factors.

The project conveyed that the BNL EVMS system description allows work to occur under two or more WADs per control account. This is not a best practice and could lead to unauthorized work starts if not closely managed. The project should reassess this approach.

Time to establish and document a strategy around subprojects seems aggressive.

Subproject strategy implementation needs to be carefully planned to meet the target dates for CD-2/3 for the first subproject.

Remaining open recommendations are appropriate but should continue to be worked to closure prior to CD-2/3 for the first subproject.

Methodology used to determine contingency is a management assessment of 10% for LOE and 35% on the remaining work. The Monte Carlo analyses presented for CD-3B were at a significantly lower percentage. The project should evaluate the contingency analysis model prior to CD-2/3 for the first subproject.

The CAMs interviewed were knowledgeable of their scope and presented traceable estimates for CD-3B scope, based on recent vendor input. To maximize the benefit, CAMs should be trained earlier in the baseline development process.

Project controls staffing should be evaluated as decisions on the organization and reporting requirements for the subproject strategy are established. It is likely additional resources will be required for the planning and execution of multiple subprojects.

4.3 Recommendations

23. Augment the project reporting to increase visibility of the procurement life cycle, to include the pre-award progress and obligation of contract award, within the next three months.

24. Develop a detailed plan to achieve CD-2/3 for the first subproject, with documented decision points, within the next three months.

25. Assure finalization of design changes and management decisions are made to allow for adequate time to support implementation of the subproject strategy before progressing to CD-2/3 for the first subproject.

5. PROJECT MANAGEMENT and ENVIRONMENT, SAFETY and HEALTH

5.1 Findings

The project received CD-3A approved at approximately $90 million and initial contracts awarded. For the CD-3A scope, four contracts have been awarded, and six are close to award. The project team prepared a CD-3A lessons learned document that analyzed seven CD-3A procurements that offered the largest learning opportunities. The lessons learned from the CD-3A long lead procurements is influencing the strategy for the CD-3B.

The CD-3B FDRs are completed and the proposed CD-3B package is not impacted by the technical finalization activities on-going in the accelerator. CD-3B is essential for mitigating project risk in preparation for CD-2. The project requests authority to execute long lead procurements with a point estimate of $52.598 million, including 35% contingency, covering 11 items of scope. The project is planning for CD-3B approval in second quarter FY 2025.

Recently, NYS committed $100 million toward construction of EIC buildings and infrastructure. The UK also announced £58 million ($75 million) for the EIC. EIC Resource Review Board Meetings in Rome in May 2024 and at BNL in October 2024. Strong participation from Canada, Czech Republic, France, India, Israel, Italy, Japan, Poland, South Korea, United Kingdom, and Taiwan. The next meeting is to be held in Prague in June 2025.

CD-2 project planning objectives and constraints include:

- Scope required for the DOE KPPs;
- Develop plans for the execution of the portfolio of off project scope;
- Project total cost less than $3 billion (working to optimize scope within this objective);
- DOE annual project funding not to exceed $300 million per year;
- EIC construction starts following the conclusion of RHIC operations; and,
- Start Early Science Program when electron-ion collisions begin.
- Project Strategy Workshop (August 2024) discussions about how best to construct the EIC facility within funding constraints. Consensus support for the phased delivery of the EIC scope and the need for follow up efforts to define subprojects aligned with the phases. The focus was accelerator phasing and early science plans.

Insufficient budgets in FY 2025 and FY 2026 will result in a longer construction schedule and scientific “dark period” than desirable. The subprojects delivery approach can mitigate it. The goal is to have SP1 ready to be approved in third quarter FY 2026.

Potential EIC Subprojects include:

- SP1 - Hadron storage ring modifications, ESR, and infrastructure
- SP2 - IR integration, IR superconducting magnets, ePIC detector
- SP3 - Electron injector systems and related infrastructure

- After the first three subprojects, the Early Science Program could be initiated
- SP4 - RF power, 41 GeV by-pass, 18 GeV capability

Requirements for subproject strategy include:

- EIC is a single, integrated line-item project.
- Subprojects will have well-defined deliverables and interfaces.
- Completed subprojects will enable the start of the EIC Early Science Program.
- Annual funding profile for the subprojects must be consistent with DOE guidance.

Updates of some project documents has been paused as a strategy for subprojects is explored. The project recognizes that big decisions have been made, and much more work needs to be done before baselining.

Project priorities for 2025 include:

- Execute the CD-3A and CD-3B procurements;
- The project's analyses and plans assume a CD-3B approval by the end of March 2025;
- Prepare plans for addressing the "portfolio" of project dependencies; and,
- Prepare the performance baseline for the entire project, define appropriate subprojects and prepare the first subproject for approval.

The project is currently optimizing technical performance, cost, and schedule to baseline most of the scope at the beginning of CY 2026, to start the science program in CY 2034. FY 2025 and FY 2026 funding uncertainties and plan for the continued ramp-up in staff, both BNL and TJNAF hires and the transition of BNL RHIC operations staff into EIC construction present a challenge. A new Technical Director was hired in January 2024.

The project cost contingency is 35% on work to go (except LOE is at 10%). There is 24 months CD-4 schedule contingency. The project currently identified two major scope contingency opportunities without compromising the ability to meet science requirements:

- Strong hadron cooling,
- Delayed purchase of RF power supplies, and
- The budget associated with these two areas is approximately $330 million.

The project developed the "Strategy Regarding IKCs and Non-US Pressure System Codes" as an appendix to the Quality Assurance Plan. The stated approach is an intention to have all IKC follow American Society of Mechanical Engineers (ASME) standards. If that is infeasible, the laboratories would pursue a variance to 10 CFR 851.

The project's assumptions document states that the EIC Project Executive Management Team will prepare an overall EIC project delivery plan including the subprojects required.

The project is proposing to focus on delivering EIC performance, which meets the Mission Need Statement for the range of Center of Mass energies from 40 GeV – 100 GeV, and peak luminosity of 10^{33} $cm^{-2}s^{-1}$ or above. Ultimate EIC performance would leverage upgrades and improvements.

Both BNL and TJNAF have drafted Proposed Commitment Plans. Some work remains to complete the drafts before approval. BNL has initiated efforts to define and quantify all of the scope, efforts and resources needed to support the construction and operation of EIC. This broader view is referred to as the EIC Portfolio. An Interim EIC Portfolio Coordinator has been named to identify the full project and off project scope of work.

The recommendation tracking sheet shows 47 total recommendations assigned to Project Management. Of those, 40 are closed, two are in progress, and four are open. Of those in progress or open, all are due by CD-2.

ESH Readiness for CD-3B

The ESH program for the EIC project is comprehensive and reflects significant progress in preparing for CD-3B activities, as well as progress toward baseline. Core documentation is in place to guide compliance and planning, including a National Environmental Policy Act (NEPA) determination confirming no Environmental Impact Statement (EIS) is required for CD-3B scope. The EIC Environmental Assessment (March 2021) provides a foundation for environmental compliance, while the Preliminary Fire Hazard Analysis (July 2023) addresses potential fire safety risks. Updates to the Hazard Analysis Report (HAR) and Integrated Safety Management (ISM) Plan align with DOE Order 413.3B requirements and demonstrate the project's increasing maturity and commitment to hazard mitigation.

To ensure consistent safety protocols, Memorandums of Agreement (MOAs) have been established for work planning and control, pressure safety, and non-NRTL (Nationally Recognized Test Laboratory) electrical equipment, reflecting alignment between partner laboratories. A draft Construction Safety and Health Plan has been developed collaboratively with input from experienced stakeholders, incorporating lessons learned from prior DOE projects such as the Proton Improvement Plan II (PIP-II; FNAL) and leveraging insights from BNL's Modernization Project Office. Initial radiological evaluations, including shielding analyses and tritium production estimates, indicate a high probability for compliance with regulatory limits. These evaluations indicate that shielding provisions and radiological monitoring strategies are robust enough to protect personnel and meet design criteria.

The ESH program actively integrates safety into all aspects of the design and construction processes. This integration is supported by regular participation in project reviews, routine collaboration with partner laboratories, and alignment with safety-focused work planning. Efforts to continuously evaluate and adapt processes, such as revisiting foundational documents considering the updated injector plan and exploring the incorporation of a construction-phase Fire Hazard Analysis, further demonstrate the program's proactive risk management. By leveraging these elements and maintaining close coordination with stakeholders, the ESH program exhibits maturity, documentation quality, and comprehensive planning necessary to support the project's readiness for CD-3B approval, and progression toward baseline.

Quality Assurance Readiness for CD-3B

The EIC project's Quality Assurance program is well prepared to meet the requirements for CD-3B. The Quality Assurance Plan (QAP) has been formally approved, leveraging established systems and frameworks at both BNL and TJNAF. This plan is continuously evolving to address project needs and ensure alignment with DOE standards and expectations. Quality control plans for all CD-3A items have been successfully completed, while those for CD-3B are either finalized or in progress. These quality control plans are designed to ensure that fabrication, assembly, testing, and installation processes meet stringent quality requirements, enabling the project to maintain high standards throughout its lifecycle.

Quality assurance is deeply integrated into design and procurement activities, with structured processes to ensure acceptance criteria, inspection protocols, and supplier evaluations are applied. This integration is supported by thorough design reviews, approval of technical specifications and statements of work (SOWs), and detailed supplier surveys and surveillance during procurement.

The project's active lessons learned program is a key enabler of continuous improvement. Lessons from prior experiences, such as the 1-cell 591 MHz cavity, are being analyzed and shared between BNL and TJNAF, and contributions to DOE OPEXShare ensure these insights inform broader DOE initiatives.

Staffing at both BNL and TJNAF is sufficient to support current and future quality assurance needs. Quality assurance teams are experienced and supported by mature systems like eTraveler and nonconformance tracking tools, which enable efficient management of quality assurance processes. However, further refinement and testing of these systems are needed, particularly around resolving Nonconformance Reports (NCRs) in a timely manner. Configuration management is supported by a plan that ensures changes to the baseline are controlled and traceable, reinforcing the integrity of the project's design and execution.

Efforts to engage IKC partners in quality assurance processes, particularly around change control and compliance with ASME standards, remain a priority. Clear documentation and coordination are necessary to align international contributions with project requirements. The project team's focus on refining tools, implementing lessons learned, and ensuring compliance across stakeholders positions the quality assurance program as a critical component of the project's readiness for CD-3B approval.

5.2 Comments

The project team has made excellent progress since the November 2023 review. There is an experienced team in place. A new Technical Director was recently hired and has already made a positive impact on the project.

The project has strong support from the BNL and TJNAF Directors. Communications between the Laboratories are well established with bi-weekly meetings between the two lab Directors and

Deputy Directors. This will be an excellent forum to facilitate constructive resolution of issues and risks as they arise.

CD-3A and CD-3B

CD-3A progress (since the March 2024 approval) has not progressed as envisioned. Over 50% of the procurements have been delayed between two and six months. Causes include deficient development of tech specs/SOWs, late review of packages by systems engineering/quality assurance, and vendor concerns with subcontract terms and conditions. The project conducted a lessons learned evaluation to understand the causes and developed corrective actions to mitigate these situations on the remaining CD-3A and future CD-3B procurements. Executing CD-3A helped the project understand the realities of long lead procurements within the current market conditions and anticipated risks. This experience and lessons learned should be put to use in planning the CD-3B long lead procurements to the fullest extent possible. CD-3B justification and motivation seem sound to mitigate risks on the project. However, the project should re-evaluate the planned procurement schedules to ensure realistic durations/milestones are established.

In-Kind-Contributions; New York State Commitment

Congratulations on receiving the NYS commitment of $100 million and the recent announcement by the UK of $75 million contribution.

Significant progress has been made on understanding known and potential IKCs from international partners. Addition of an EIC IKC engineer is a positive development. The project does not intend to use science and technology (S&T) agreements, but rather I-CRADAs (Cooperative Research and Development Agreement and Project Planning Documents (PPDs) to document agreements and understandings. The project should be cautious about:

- Confusion or complexity caused by segregated documents between TJNAF and BNL.
- Mindful of complications that can be caused by sensitive countries, S&T risks, and export control.
- Having a means to share draft PPD information with partners that is in compliance with DOE P 485.1.
- Prepare to efficiently finalize documents, obtain DOE review and approval. For the initial development and inevitable updates after signature.
- Determine how smaller or less risky hardware contributions will be managed.
- Document and manage ePIC Collaboration effort contributions to such things as installation/integration and computing.

It is not clear at this time what kind of special considerations might be needed for specific IKC partners. For example, willingness to sign I-CRADAs, exceptions to expectations, etc. At a future review, present the resources needed to coordinate with IKC partners and quantified risks driven by IKC approach.

Path to Baseline

The project presented a subproject strategy that would maintain project momentum and progress made to date and to mitigate schedule risks that could be imposed by potential funding constraints. However, the strategy decision was recently made and there was insufficient time for the project to develop the details necessary for the Committee to assess the validity of the scope, cost, and schedule of the subprojects along with the benefits cited. The pivot to subprojects and preparing to baseline Subproject 1 will take considerable planning and preparation by the project team and must be done in parallel to socializing with stakeholders and aligning support.

The project's notional subproject approach has SP1 through SP3 providing all that is needed for early science and meets a minimal interpretation of Mission Need Statement. SP4 was stated that it would align to the ultimate performance parameter and more optimally meet the intent of the MNS. However, not all stakeholders are currently aligned on how to interpret the intent of the MNS. Several factors will weigh into the decision of the subproject strategy, including:

- Identify and articulate the scope of the EIC project and KPPs.
- Development of the funding profile with known constraints such as annual peak funding, and redirection priority of RHIC operations funds.
- Maturity (design and cost) of the recent technical design changes.
- Development of off project dependencies.
- Integration of the subprojects to ensure interface points are clearly delineated.
- Develop preliminary time-phased contingency requirements for proposed subprojects.
- Project should carefully plan additionally project support staff (e.g. procurement) to meet the need for subprojects.

The Committee believes the project should be cautious of moving too quickly with the strategy until these issues are fully understood.

The Laboratory and project will need to actively manage transition of RHIC staff as RHIC operations cease at the end of 2025. It will be important for the project to fill three key positions that will soon be vacated by retirements.

Due to the recent technical decisions, the project did not present all of the considerations and implications of the accelerator system design changes. This includes science reach impacts, siting concerns, life cycle cost impacts, etc.

The project team should consider assessing post-mitigation contingency used for project contingency allocation to ensure estimate is not understated. The outputs of their contingency analysis may understate the needs at this phase of the project. The project team should develop a plan for cost allocation of common LOE. Use of design labor estimates as the basis for measuring a cost-weighted design maturity index could result in fluctuations if design efforts are not accurately estimated up front.

The development of an overall EIC project delivery plan is encouraged with roles and responsibilities defined in a way to avoid disconnects caused by the subproject strategy. The recent approach to establish an Interim EIC Portfolio Coordinator is already providing value in making the entire EIC enterprise visible and the need to understand interdependencies and interfaces. The Committee encouraged the project team to utilize a systems engineering approach to the extent appropriate to manage requirements and interfaces across the entire EIC portfolio. BNL must work more expeditiously to inform DOE on the scope and cost of the EIC Portfolio. This is essential to inform budgetary planning at BNL and DOE/NP and to inform essential decisions needed to facilitate project planning and execution. BNL should proactively define how constraints and trade-off decisions will be expeditiously resolved when needed annual resources for the EIC portfolio are not met.

The project is encouraged to further leverage lessons learned on subprojects to inform their planning. Technical interfaces, funding uncertainties and dependencies require a high level of flexibility. This should be done by both the project and DOE.

Use of subprojects offer an opportunity to improve the focus of management and DOE oversight and engagement. Both the project and DOE should leverage that opportunity.

ESH

For ESH, completing radiological evaluations remains a high priority as they will inform the infrastructure design and baseline decisions. Revisiting project documents considering the updated injector plan is critical to ensuring alignment with current project objectives and regulatory requirements. The construction phase Fire Hazard Analysis and reassessment of the HAR matrix scale will further enhance the project's preparedness for managing risks. Adapting to the EIC subproject model will require a cohesive strategy to ensure safety considerations remain integrated across all phases.

For quality assurance/quality control, the project team should focus on clarifying how change control processes are coordinated among various stakeholders, particularly the IKC partners. Fully testing and exercising quality assurance/quality control tools, including resolving NCRs efficiently, will be essential for ensuring these systems function as intended. The lessons learned from past experiences, such as the 1-cell 591 MHz cavity, provide valuable opportunities to refine processes, and the project should present these findings in future reviews. Ensuring ASME compliance with international partners is another critical step that needs ongoing attention. Adapting the quality assurance/quality control framework to the EIC subproject model will ensure that quality oversight continues to support the project's evolving structure effectively.

5.3 Recommendations

22. Proceed to CD-3B.

Path to baseline:

23. In advance of the next DOE/SC review, document the scope of EIC project and gain alignment with the program office on mission need achievement.

24. Develop details for the subproject strategy and work with the program office and Federal Project Director to conduct a focused DOE/SC review in six months. See details in the comment section.

Appendix A Charge Memo

United States Government **Department of Energy**

memorandum

DATE: November 07, 2024

REPLY TO ATTN OF: Office of Nuclear Physics (NP)

SUBJECT: Long-lead Procurement Critical Decision Review of the Electron-Ion Collider project (EIC)

TO: Kurt Fisher, Director
Office of Project Assessment (OPA)

I request your Office organize and conduct a Department of Energy (DOE) Office of Science (SC) long-lead procurement Critical Decision (CD) review of the Electron-Ion Collider project (EIC) at Brookhaven National Laboratory (BNL), for both in-person and remote participation, January 7 to 9, 2025. The purpose of this review is to assess the overall status of EIC to include its technical definition, schedule, cost, management, environment, safety, & health (ES&H), and quality assurance (QA) as it executes long-lead procurements approved at CD-3A, Approve Long Lead Procurement, prepares for CD-2, Approve Performance Baseline, and to determine if it can successfully request CD-3B, Approve Long Lead Procurement.

The EIC project attained CD-1, Approve Alternate Selection and Cost Range, with a preferred alternative of strong hadron cooling and a cost range of $1.7 billion to $2.8 billion, on June 29, 2021 and CD-3A, Approve Long-lead Procurement, with scope associated with the accelerator, infrastructure, and detector, on March 28, 2024. The EIC will enable scientists to investigate the basic building blocks of nuclei and how quarks and gluons, the particles inside neutrons and protons, interact dynamically via the strong force to generate the fundamental properties of neutrons and protons, such as mass and spin. In carrying out its charge, the review panel is requested to consider the following topics:

1. Is the project team effectively executing the work, including the long-lead procurements authorized by CD-3A? Is the project positioned to complete CD-3A scope within the established schedule and cost baseline? Are technical issues appropriately and proactively being addressed?
2. Are R&D and design efforts yielding sufficiently advanced designs and mitigating technical risks, particularly in strong hadron cooling? Are the proposed CD-3B long-lead procurements appropriate and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements attained final design?
3. Is the project making adequate progress developing the performance baseline? Is the project scope defined well and logically? Are the schedule and cost estimates credible? Do plans include adequate scope, schedule, and cost contingency? Are estimates for the proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly?
4. Are ES&H and QA properly addressed given the project's current stage of development?
5. Is the project properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3B scope? Are roles and responsibilities documented and understood?
6. Has the project satisfactorily addressed recommendations from previous DOE SC reviews?
7. Is the project ready for CD-3B approval?

The Office of Nuclear Physics Program Manager for Major Initiatives, Ivan Graff, will support you as necessary to plan and carry out this review. I would appreciate receiving the report within 60 days of the review's conclusion.

Linda L Horton — Digitally signed by Linda L Horton Date: 2024.11.15 12:56:08 -05'00'

Linda L. Horton
Acting Associate Director of the Office of Science
for Nuclear Physics

cc:
Alex Bachowski, SC-OPA
Robert Caradonna, BHSO
Bryan Foley, TJSO
James Yeck, BNL

Appendix B Review Committee

DOE/SC Status/CD-3B Review of the
Electron Ion Collider (EIC) Project at BNL
January 7-9, 2025

Kurt Fisher, DOE/OPA, Chairperson

SC1 Injectors (WBS 6.03)	SC2 Collider (WBS 6.02; 6.04, 6.05; 6.06)	SC3 Global Accelerator Systems (WBS 6.07; 6.08; 6.09)	SC4 Detector (WBS 6.10)
* *John Lewellen, LANL*	* Jie Wei, MSU	* Daniel Ratner, SLAC	* Dave Christian, FNAL
Anna Alexander, LANL	Fulvia Pilat, ORNL	Dan Gonnella, SLAC	Claude Pruneau, Wayne State
Axel Brachmann, SLAC		Peter Ostroumov, MSU	
Fernando Sannibale, LBNL		Guobao Shen, ANL	

SC5 Infrastructure (WBS 6.11)	SC6 Cost and Schedule (WBS 6.01)	SC7 Project Management (WBS 6.01, 6.12)
* Jeff Sims, MSU	* Duke Hughes, ORNL	* Hanley Lee, DOE/SSO
Alex Bachowski, DOE/OPA	Janet Bivens, ORNL	Adam Bihary, DOE/FSO
Piper Kujac, LBNL		Vince Guiseppe, ORNL
		Duane Newhart, MSU (ESH)
		Kurt Vetter, FNAL

Observers

Linda Horton, DOE/NP	*Michelle Shinn, DOE/NP*
Paul Mantica, DOE/NP	Robert Caradonna, DOE/BHSO
Manouchehr Farkhondeh, DOE/NP	Daniel Rachal, DOE/BHSO
Ivan Graff, DOE/NP	Caroline Polanish, DOE/BHSO
Elizabeth Bartosz, DOE/NP	Tim Alba, DOE/BHSO
Kenneth Hicks, DOE/NP	Bryan Foley, DOE/TJSO
Spyridon Margetis, DOE/NP	Allena Opper, NSF

LEGEND

SC Subcommittee
* Chairperson
ITA Remote Participant

Count: 23 (excluding observers)

Appendix C Review Agenda

DOE/SC Status/CD-3B Review of the
Electron Ion Collider (EIC) Project at BNL
January 7-9, 2025

AGENDA

Day 1
Tuesday, January 7, 2025
Building 488 Berkner Auditorium
ZOOM: https://bnl.zoomgov.com/j/1604678415?pwd=IT6oTzz6dOLM6sROWPCEYqoBdkn1AR.1

start - finish	Title	Speaker	duration/min
8:30 AM - 9:30 AM	**Full Executive Session**		60
9:30 AM - 9:35 AM	Welcome	J. Hewett/K. Sawyer	5
9:35 AM - 10:20 AM	Project Overview	J. Yeck	45
10:20 AM - 11:00 AM	Project Management Overview / CD-3B LLP Package	L. Lari	40
11:00 AM - 11:15 AM	*Break & Group Photo*		15
11:15 AM - 11:55 AM	Accelerator Progress / CD-3B LLP	S. Nagaitsev	40
11:55 AM - 12:25 PM	Detector Progress / CD-3B LLP	R. Ent/ E. Aschenauer	30
12:25 PM - 1:30 PM	*Lunch & PM (SC7) Interview session*	All	65
1:30 PM - 1:55 PM	Infrastructure Progress	C. Folz	25
1:55 PM - 2:20 PM	Technical Design Process & Maturity	K. Wilson	25
2:20 PM - 2:45 PM	Developing Performance Baseline CD-2, CD-3B	C. Lavelle	25
2:45 PM - 3:10 PM	Environmental, Safety, and Health	C. Schaefer/W. Rainey	25
3:10 PM - 3:20 PM	Summary of CD-3B Readiness and Discussion	J. Yeck	10
3:20 PM - 3:35 PM	*Break*		15
3:35 PM - 5:00 PM	**Breakout Sessions** - *(Transition to Bldg 510/515)*	All	85
5:00 PM - 6:30 PM	**Full Executive Session**		90
6:30 PM - 6:40 PM	Travel to Berkner	All	10
6:40 PM - 8:40 PM	Dinner at Berkner Hall	All	120

Day 2
Wednesday, January 8, 2025
Building 510 & 515
ZOOM: https://bnl.zoomgov.com/j/1604678415?pwd=IT6oTzz6dOLM6sROWPCEYqoBdkn1AR.1

start - finish	Title	Speaker	duration/min
8:30 AM - 9:30 AM	Responses to Questions	J. Yeck	60
9:30 AM - 9:45 AM	*Break (Bldg 510 Lounge)*	All	15
9:45 AM - 12:00 PM	**Breakout Sessions**	All	135
12:00 PM 1:00 PM	*Lunch*		60
1:00 PM - 4:00 PM	**Breakout Sessions**	All	180
4:00 PM - 5:00 PM	**Subcommittee Executive Sessions**	SC Chairs	60
5:00 PM - 6:00 PM	**Full Executive Session**		60

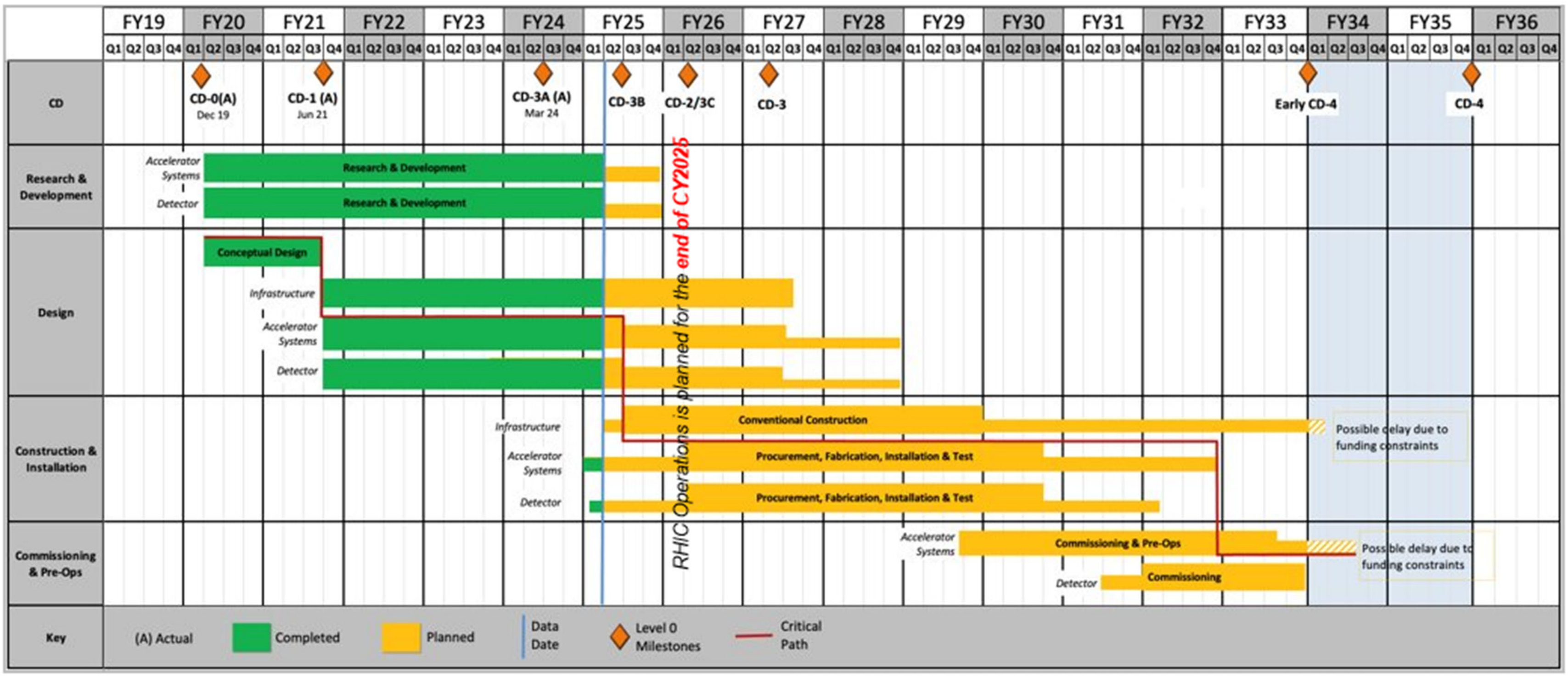
Day 3
Thursday, January 9, 2025
Building 510, 515 & 1005S
Closeout ZOOM:

start - finish	Title	Speaker	duration/min
8:30 AM - 11:00 AM	**Subcommittee Executive Sessions/Report Writing**	SC Chairs	150
11:00 AM - 12:30 PM	**Full Executive Session/ Dry Run with working lunch**		90
12:30 PM - 1:30 PM	Closeout	All	60
1:30 PM - 1:45 PM	Shuttle Pick-Up		15
1:45 PM - 3:15 PM	Tour (Sign-up only)	E. Aschenauer/K. Smith/F. Willeke	90
3:15 PM - 3:30 PM	Shuttle Drop-off		15
3:30 PM - 4:45 PM	Debrief for *EIC Team Only*	J. Yeck	75

Appendix D EIC Cost Tables

L4 WBS	LLP Category	LLP Item	LAB	CAM	Total Cost (Burd&Esc)
6.04.02.01	ESR Dipole Magnets	Electron Storage Ring (ESR) Dipole Magnets	BNL	G. Mahler	8,753,377
6.04.02.01	ESR Dipole Magnets	Electron Storage Ring (ESR) Dipole Magnets	BNL	G. Mahler	3,064,872
6.04.02.01	ESR Dipole Magnets	Electron Storage Ring (ESR) Dipole Magnets	BNL	G. Mahler	3,145,652
6.04.02.01	ESR Dipole Magnets	Electron Storage Ring (ESR) Dipole Magnets	BNL	G. Mahler	1,697,498
6.04.02.01	ESR Dipole Magnets	Electron Storage Ring (ESR) Dipole Magnets	BNL	G. Mahler	1,697,498
6.04.02.02	APS Sextupole Refurbishment	Advanced Photon Source (APS) Sextupole Magnet Refurbishment, Testing, and Measurement	BNL	G. Mahler	2,197,115
6.04.02.04	APS Sextupole Refurbishment	Advanced Photon Source (APS) Sextupole Magnet Refurbishment, Testing, and Measurement	BNL	G. Mahler	130,823
6.04.02.04	ESR Magnet Measurement	ESR Magnetic Measurement and Bench	BNL	G. Mahler	1,296,665
6.04.03.01	ESR Magnet Measurement	ESR APS Quadrupole Magnetic Measurement Stand	JLAB	S. Philip	944,689
6.04.03.01	APS Quad Refurbishment	APS Quadrupole Magnet Refurbishment, Testing and Measurement	JLAB	S. Philip	4,176,483
6.10.05.01	PbWO4 Crystals	Lead Tungstate Crystals for the Detector Backward Electro-Magnetic (EM) Calorimeter - Batch 3 and Batch 4	BNL	A. Bazilevsky	1,341,979
6.10.05.01	PbWO4 Crystals	Lead Tungstate Crystals for the Detector Backward Electro-Magnetic (EM) Calorimeter - Batch 3 and Batch 4	BNL	A. Bazilevsky	1,349,417
6.10.05.02	Scintillating Fibers	Scintillating Fibers for the Detector Barrel - Batch 2 and Forward - Batch 2 EM Calorimeters	BNL	A. Bazilevsky	1,623,220
6.10.05.03	Scintillating Fibers	Scintillating Fibers for the Detector Barrel - Batch 2 and Forward - Batch 2 EM Calorimeters	BNL	A. Bazilevsky	554,743
6.10.06.03	Forward HCal Steel	Steel for the Detector Forward Hadronic Calorimeter	BNL	O. Eyser	1,088,530
6.10.07	Detector Solenoid Magnet	Detector Solenoid Magnet Power Supply	JLAB	R. Rajput Ghoshal	697,470
6.10.08	Detector Electronics	Detector Electronics Versatile Link Plus Transceiver (VRTX+) and low Power Giga-bit transceiver (1pGBT)	JLAB	F. Barbosa	1,733,364
6.10.10.02	Detector Endcap Structures	Detector Endcap Structures – Flux Return Steel	BNL	R. Sharma	3,468,233
					38,961,630

Appendix E EIC Schedule Chart



Critical Path is Accelerator Systems

Appendix F EIC Funding Chart

EIC Proposed Annual Funding Plan, Version 4.2, Prior to FY2025 PBR ($M)

FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	Total
11	30	183	70	98	150	300	300	300	300	300	254	222	165	120	2,803

Appendix G EIC Management Chart