CD-3B Director's Review Committee Report

on the

Electron-Ion Collider

November 17, 2024

Introduction

At the request of James Yeck, Electron-Ion Collider (EIC) Project Director/Associate Laboratory Director, a Director's Review (DR) of the EIC Project was held at Brookhaven National Laboratory (BNL) on October 22-24, 2024. The purpose of this review was to assess the project's readiness for the DOE Critical Decision-3B (CD-3B) Independent Project Review (IPR), scheduled for January 7-9, 2025.

The charge for the EIC CD-3B DR is provided in Appendix 1. The committee, consisting of 35 subject-matter experts, was divided into seven subcommittees as detailed in Appendix 2. Each subcommittee had a chair to guide the compilation of comments in the subcommittee report. The primary materials reviewed by the committee included management presentations, draft DOE documentation and a large number of supporting documents. EIC review materials can be obtained by contacting James Yeck, or Alyssa Petrone, EIC Project Chief of Staff.

Members of the EIC project team presented the project's management, planning, cost, schedule and technical features (accelerator design and beam dynamics, accelerator systems, detector systems, infrastructure, ES&H), a detailed long-lead CD-3B procurement package and the plans to deliver and manage the procurements, as well as an overall status of the EIC project including project risks and potential risk mitigations.

This document is the final report of the EIC CD-3B Director's Review and contains top-level answers to the charge questions assigned to each subcommittee, as well as individual subcommittee reports organized into findings, comments, and recommendations.

Figure 1 – The EIC Project team and Director's Review Committee on October 22, 2024.

Summary Remarks

The 2015 NSAC Long Range Plan committee recommended the EIC as the next major nuclear physics facility for the US Nuclear physics program, with luminosity up to $10^{34}cm^{-2}s^{-1}$ and center of mass energy in the range of 20 - 100 GeV initially, and highly spin polarized electrons, protons, and light ion beams. The EIC will provide unprecedented capability for understanding the interaction of elemental quarks and gluons that form the basic structure of atoms and nuclei.

The committee commends the project team on continuing to advance the technical design since CD-1. The BNL and JLab teams have the requisite experience and are working very effectively for this stage of the project. While acknowledging the substantial progress that has been made in developing of the performance baseline, the timeline presented for achieving CD-2 seems optimistic given the decisions yet to be made, which at a high level are:

- **Accelerator Scope** – The proposed changes to the Injector and Rapid Cycling Synchrotron (RCS) are substantial. Technical choices need to be made as soon as possible in order to finalize the scope and establish a baseline with updates to the associated schedule, cost estimate, risks and mitigations, and project documents.
- **Subproject Strategy** – Once the technical choices on the full scope of EIC are settled, the work required to pivot into a subproject framework will take time for a project of this magnitude. Discussions with DOE-NP, the nuclear physics community, and BNL, JLab and international in-kind partners will be necessary to optimize the Key Performance Parameters (KPPs), cost, schedule, risk/contingency approach, and project documents.
- **External Dependencies** – The substantial and varied portfolio of external projects which EIC is dependent upon, is not yet fully in place. While some external projects (e.g., RHIC R&R) are maturing, others have not determined the project scope or the resources (funding and people) necessary for successful execution. BNL and JLab leadership are urged to make the necessary laboratory decisions and modifications to align with the EIC requirements.

The committee has full confidence that the leadership of BNL, JLab and EIC are capable of addressing these challenges, but it is important to work decisively and in coordination with each other.

Overall the committee strongly endorses the CD-3B package and finds that the project is ready for DOE approval for this package. The CD-3B long-lead procurement (LLP) package is

strategically advantageous for the project, particularly with respect to reducing risks associated with supply chain issues and vendor uncertainty, and is not impacted by the technical finalization of the injector and RCS. The CD-3A LLPs scope is progressing but with many procurement delays driven primarily by technical changes. There are likely CD-3A "lessons learned" (e.g., Procurement Liaison Engineers) that should be applied to the CD-3B package.

Finally, the committee is concerned that EIC is relying on a top-down approach to contingency that results in 28.7% contingency for the total project. It is understood that risks and uncertainties will be refined ahead of CD-2, but current risk register inputs and project context make clear that contingency, as presented, is marginally low. At the upcoming IPR, the project should be prepared to discuss the plan to define a level of risk-based contingency that would support the baseline.

The project is ready for CD-3B, and should proceed to the DOE-SC OPA CD-3B review.

Subcommittee Reports

SC1 – Injectors

Findings

- There are no selected components in the Injector System for CD-3B Long-Lead Procurements (LLP). Current version of the LLP list is focused on critical components for ESR and detector. On the other hand, the injector design is still maturing.
- The cost for the injector SC linac is estimated at 200 M$, while the cost of RCS is at 214 M$. There are some items missing in these cost estimates.
- The committee congratulates the team on the success of the development and commissioning of the polarized gun project.
- RCS cable distribution in a tight RCS tunnel is a big challenge.
- To meet the Mission Need Luminosity of 10^{33}-10^{34} cm^{-2} s^{-1}, the Injector needs to preserve ~90% polarization at high bunch charge. The RCS should deliver:
    - 28nC bunch to 5 or 10 GeV and fill 1160 bunches in ESR in <20 min. The fill rate is 3 bunches in 1.5 sec. The depolarization time is long enough that swap-out bunch replacement is not needed in this mode.
    - 11nC bunch to 18 GeV and fill 290 bunches in ESR at 1 Hz. Continuous swap-out bunch replacement at 1 Hz is required due to short depolarization time.
- Polarized photoinjector (SL-GaAs) demonstrated up to 11.6nC per bunch with 85-90% polarization. Front end design includes two 45-deg Wien filter to rotate spin from longitudinal to vertical.
- Commercial 400-MeV NC linac replaced by a 3GeV SC linac (1.3 GHz) as RCS injector. The higher injection energy addresses the issues with low magnetic field at injection in RCS.
- Scheme to fill 28nC per bunch: 3 trains of 4 7nC bunches each transferred into RCS where the charge accumulates via off-momentum injection into the same RF bucket. Dispersion at injection straight is required. Damping wiggler may help to shorten damping time at injection energy.
- A phased approach was proposed. Phase 1: 7-nC bunch injected on-axis and accelerated in RCS to 5 or 10 GeV; possibly lower injection energy. Phase 2: three 28-nC bunches stacked longitudinally and accelerated in RCS to 18 GeV. Damping wiggler added.
- Multiparticle beam have been tracked through the linac and RCS at 7.5nC; impedance was included. Polarization preservation has been modeled.

- Significant CSR blowup of horizontal emittance observed in linac to RCS (LTR) transport.
- Standard septum and kicker parameters for RCS.
- Dispersion at RF cavities was not included.
- Beam-RF effects were not presented.
- 28nC accumulation simulations still need to be done.
- The total number of RCS magnets and BPMs was reduced in a cost-cutting exercise.
- RCS extraction modeled, including study of septum and kicker parameters. For 18GeV, RCS/ESR swap-out dump conceptual design developed using Cu dump material.
- RCS impedance model is dominated by resistive wall. Most high-count components (e.g. BPMs, bellows, etc) are included; model is 60%-70% completed. In Phase 1, TMCI threshold is ~6 times above the bunch current. In Phase 2: energy spread must be blown up 5x above equilibrium energy spread to stabilize TMCI and MWI; this is provided by damping wiggler.
- To minimize eddy currents during rapid 100ms ramp, RCS vacuum chamber is stainless steel. Cu coating is used to reduce resistive wall impedance. The chamber aperture is round with 40mm diameter, even in dipoles.
- The project team is assessing 3-18 GeV accelerator options alternative to RCS.

Comments

- The committee congratulates the team with the impressive progress on the injector design since the last DR. The committee found that a strong team was developed at EIC, in collaboration with outside partners. The committee finds the team is capable of addressing the remaining design challenges.
- For the upcoming DOE CD-3B review, the committee suggests the following:
    - Include slides on system cost, schedule, and status, clearly state successes on reaching project milestones, and state which charge question is being addressed.
    - Ensure consistency in what is and isn't included in the cost. Clarify schedule with respect to fabrication, delivery, and testing.
    - Technical details should be high level and focus on project milestones.
    - Ensure sufficient time for Q&A to avoid misunderstanding by the reviewers.
    - Considering the maturity of injector development, the tone of the conclusions should reflect the remaining uncertainties.
    - The talks should focus on progress to CD-2, which includes the risks and their mitigation.

  - SC1 presentations are missing detailed discussion on the RF design for linac and RCS and impact on performance.
  - The presented alignment tolerances for RCS magnets were confusing. Add clarity for the upcoming January OPA review.
- Several major risks for RCS injector are being effectively addressed (linac, injection to RCS).
- The current RCS design is incomplete and still exhibits multiple risks:
  - Space constraints in the RHIC tunnel negatively affect the optics symmetry
  - Install/maintenance issues
  - Interaction of RCS ramping fields with collider operations
  - Remaining uncertainties with the polarization performance
  - Beam dynamics during injection and merging
  - Details of RF
  - Management of heat loads in the RHIC tunnel
  - Multiple RCS element interferences with the other equipment inside the tunnel
  - Specification of Damping Wigglers
  - Dispersion matching at the RCS injection point
- Considering the magnitude of the remaining risks (as presented), a search for a second design option for the RCS to address both technical and operational risks is warranted. More detailed cost comparison should follow.
- The committee endorses the phased approach for the injector. This could provide more time for detailed and optimized RCS design and cost optimization.
- The committee is concerned with the cost estimates for RCS and linac as presented. The committee feels that there is ample room for cost optimization and validation, especially with respect to the recent US light source projects, such as APS-U and LCLS-II-HE.
  - A more thorough cost estimate of the proposed SC 3GeV linac including a new tunnel, cryomodules, RF transport, support gallery, PPS, ODH, water cooling, cryo-plant, cryo-transport, extra modules from beam loading phasing, LLRF, controls, ... is warranted.
- High bunch charge injection into the RCS should include analysis of beam-RF interaction, dispersion at RF, and include beam loading compensation. Synchro-betatron coupling + impedance can limit the bunch charge (observed in APS booster).
- The lack of a design for the 5-cell 591 MHz rf cavities is a schedule concern.
- Conclusions from transverse instability analysis indicate room for optimization in terms of the size and shape of the dipole vacuum chambers. The performance / cost benefits of the round versus elliptical vacuum chamber in the RCS dipoles should be evaluated.

- CSR increases the horizontal beam emittance 6-fold after the 3GeV transport line, which is concerning.
- The team did not show start to end beam performance tracking from the gun to the ESR including orbit correction with fewer BPMs and the effect on polarization preservation. A thorough error analysis and orbit correction simulations should be presented during the next status review. The analysis should include polarization dynamics during off-energy injection in RCS with errors.
- Consider alternative materials to Cu for the RCS/ESR beam dump to avoid surface damage (take advantage of R&D on collimators and dumps at APS and CERN).
- Consider COTS for distributed BLM.

Recommendations

1. Benchmark the costs for linac and RCS with that of recent DOE and other projects (LCLS-II-HE, APS-U, ILC, EU XFEL).
2. Investigate alternative injector designs and optimization options to address the RCS technical risks.
3. Considering the magnitude of the technical challenges, the committee recommends prioritizing sufficient time and resources to determine/detail an optimized solution for the electron injector by CD-2.
4. Prior to CD-2, complete a start-to-end tracking simulations of the electron injector beam showing polarization preservation.
5. Prior to CD-2, organize a review including RHIC staff to determine feasibility and operation issues of RCS sharing the same tunnel with ESR and HSR.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues bring proactively addressed? ***Yes.***

2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling? ***Qualified yes. Recently the project assessed and quantified the risks associated with the electron injector and is in the process of planning their mitigation.***

3. Are proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are estimates for proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly? ***Not applicable for Injector Systems.***

4. Is the project making adequate progress in 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? ***Qualified yes. The team has made the good progress since the 2023 Director's Review. However, the EIC electron Injector still has the lowest technical maturity among other project subsystems. There are additional opportunities that should be investigated. See recommendations.***

6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood? ***Yes.***

7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Yes.***

8. Is the project ready for CD-3B approval? ***Not applicable. No CD-3B scope for the Injector.***

SC2 – Collider

Findings

- The collider technical studies and engineering have made strong progress since the CD-3A Directors Review a year ago. The EIC designs for the magnets, vacuum systems, injection, controls, interaction region, utilities, and LEC have all moved well into the next stage.
- The EIC accelerator physics studies have been extensive, supporting the present design choices and engineering.
- The project now plans to start proton operation with precooling at injection energy in the HSR, based on the demonstrated LEReC cooling technology, and without cooling at full energy. High energy cooling of proton beams can still be implemented after project completion.
- To regulate the cavity fields, a LLRF system from BNL may be used.
- ESR Magnets – the CD-3B scope includes the following:
    - Magnet steel for all ESR dipole magnets
    - Production of 128 D1/D3 and 64 D2 magnets
    - Labor and materials to refurbish 264 sextupole magnets obtained from the APS
    - Labor and material to refurbish and rebuild 400 quadrupole magnets obtained from the APS.
    - All labor associated with measurement of 128 D1/D3 magnets, 64 D2 magnets and four first of series magnets.
    - All labor associated with field quality measurements of 264 Sextupole magnets.
    - All labor associated with field quality measurements of 120 quadrupole magnets.

- All labor and materials for procurement of magnetic measurements and two new test benches.
- Costs associated with shipping, vendor oversight, Qc, documentation, etc.

Comments

- The new beam cooling scheme with proton pre-cooling at injection energy in the HSR and initially no High Energy Cooling removes a major risk item, with a still acceptable performance for the start of operation.
  Performance for e-A operation now would greatly benefit from stochastic cooling at full energy, using the technique demonstrated in RHIC.
- Most of the shown funding profiles for the construction of the various accelerator components peak in the years 2027 to 2029. An exercise is suggested to see if the required funding and personnel needs can be leveled over a longer time frame.
- The amorphous carbon coating of the beam screens was very successful and have yielded SEY values close to 1.0. The possible generation of larger macroscopic dust-like particles, that could affect the beam, should be checked.
- The crab cavity fields at the ends of the bunches should be studied further to see if they have effects on sustained beam polarization in the HSR, including not fully compensating crab cavities.
- Beam-beam simulations should include the beam rotation due to detector solenoid and crabbing, simultaneously.
- The LEC in the HSR has a 13 MeV 70 mA beam. Attention should be paid to the effects of beam loss along the beam line over extended operation.
- A study of the loss monitors in the IR should be carried out to see if the losses in each ring can be independently measured. Modest modification to the detectors may help.
- The cryostats in the IR must handle SC magnets, support the weight, suppress backgrounds from the beam, absorb synchrotron radiation, mitigate HOM generation and heating, reduce backgrounds from masks, protect the IR SC magnets from beam quenching, incorporate heavy metal shielding, and other effects. Simulations and related mitigations of all these effects should continue. (e.g. SuperKEKB and Belle II have experienced significantly larger backgrounds during beam operations than anticipated).
- The injection kicker stability requirements should be clearly presented at the next review.
- IR Magnets:
  - The Committee finds the proposed scope for the ESR magnets to be appropriate for CD-3B.

- The new WBS structure puts much needed emphasis on the challenging superconducting magnets for the IR.
- The addition of a Magnet Steering Group made up of outside experts is an excellent idea. EIC should make full use of this added resource.
- The 9 direct wind and 6 cable superconducting magnets are all unique units, and will have no spares. Many of these magnets go beyond what has been demonstrated, and if any of these magnets is not available on time it will delay the entire project. This presents a very high risk, which is presently insufficiently mitigated.
- The committee encourages effort to support the technology decision by building a short version of a Q1ABpF magnet using the direct wind technique and a B1pF cable magnet.
- External partnerships should be aggressively pursued.

Recommendations

1. Evaluate options to reduce the risk associated with 15 unique IR superconducting magnets.
2. Prior to setting the performance baseline, conduct a comprehensive risk assessment of the Cable and Direct Wind SC IR magnets, determine if a spares program is warranted and if any spares should be included in the baseline plan.
3. In preparation for CD-2/3, a) expedite the development of collider operation scenarios in case crab cavities do not meet nominal values; b) quantitatively evaluate luminosity degradation due to emittance growth from beam-beam with noise and IR nonlinearities; c) analyze beam-beam depolarization.
4. Carryout the next round of IR MDI studies to see if background and HOM simulations indicate changes to the IR cryostat and beam chambers concerning heat loading, radiation shielding, backgrounds, masking, and quenching.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3B performance baseline, and are technical issues bring proactively addressed? ***Yes, and yes for CD-3B scope.***

2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling? ***Yes, the team is working on the relevant items. Cooling configuration with LEC has eliminated (or at least postponed) the strong hadron cooling risk.***

3. Are proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are estimates for proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly? ***Yes, for appropriateness, mostly for final design completion.***

4. Is the project making adequate progress in 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? ***The collider rings project team is making adequate progress. The schedule for the new IR magnets is challenging (see comments and recommendations).***

6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood? ***Yes, for strong hadron cooling, CD-3A and CD-3B.***

7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Mostly, see comments and recommendations***

8. Is the project ready for CD-3B approval? ***Yes, pending successful FDR for ESR dipole magnets.***

SC3 – Global Accelerator Systems

Findings

- Accelerators Installation and Removal
    - The project is considering replacing Strong Hadron Cooling (SHC) with Low Energy Cooling (LEC), and using a 3 GeV, 1.3 GHz SRF injector for the RCS.
    - EIC received 400 quads and 280 sextupoles from APS. Several units have been tested. Remaining testing and refurbishment in CD-3B. This is estimated to save ~ $7M.
    - RHIC component removal from the tunnel is covered off-project.
    - R&D programs are underway for many accelerator systems (magnets, power supplies, cavities, vacuum chambers, etc.).
    - A mock beam screen insertion test was performed in response to an IPR recommendation.
    - Automated tooling is being developed for removal and installation of accelerator components.
    - An EIC integrated C-AD model exists and is managed by a single person for each geographic area of the machine.
    - CD-3A and CD-3B procurements are at or near the planned installation critical path.

- The Accelerator Systems Installation team manages integration and interface design for installation and removal of accelerator systems. This includes the budget and schedule.
- Installation cost and schedule estimation presented is based on CD-1 and are being updated for CD-2 based on the new EIC configuration plans.
- 3D Models are in place and can be used for tools similar to what SLAC has for cable plant design.
- Subsystem teams are responsible for the installation planning of their systems. There is currently no integrated installation team. Joe or his replacement will manage installation including work planning.
- The installation deliverable is systems ready for integrated test (commissioning).
- Bottoms up cost estimate in progress. Common tool for BOEs across all systems (good). Off-project deliverables are being moved into the EIC P6 schedule.

- Controls
  - During a drill down into the LLRF PDR documentation there were several documents that were incomplete and/or not signed off.
  - Continuous Integration and Continuous Deployment is in focus and a best practice.
  - The team is working on bridging the gap between ADO based controls and EPICs. There is a good team in place.
  - Phoebus is the latest version of CS Studio used at BNL.
  - The increase in controls FTEs over the next year is concerning. 15 additional in FY25, primarily from C-AD. The need for training is understood.
  - The common platform is pervasive, maybe too much i.e. Vacuum.
- RF Systems
  - The EIC RF scope is detailed in the table below:

RF System	Function	Quantity	IKC	System Type	Frequency	RF Power
ESR – IR10	Storage	17	--	SRF 1-cell	591 MHz	800 kW
RCS – IR10	Acceleration	4	4	SRF 5-cell	591 MHz	70 kW
HSR – IR10	Storage	5	--	SRF 1-cell	591 MHz	70 kW
HSR – IR4	Storage	7	--	NCRF 1-cell	197 MHz	65 kW
HSR – IR4	Re-Bucketing	4	--	NCRF – QWR	98.5 MHz	120 kW
HSR – IR4	Re-Bucketing	3	--	NCRF – QWR	49.2 MHz	120 kW
HSR – IR4	Capture/Accel	4	--	NCRF – QWR	24.6 MHz	120 kW
HSR – Crab	Main Crab	8	--	SRF – RFD	197 MHz	75 kW
HSR – Crab	Crab 2nd Har.	4	4	SRF – RFD	394 MHz	35 kW
ESR – Crab	Main Crab	2	2	SRF – RFD	394 MHz	35 kW

- ESR 591 MHz 1-cell cryomodule and crab cavity are high risk in the risk registry
- Requirements are still being developed, systems engineering group is engaged.
- Dependencies are mapped which will support IRDs in the future.
- Issues were found with first article ESR 591 MHz 1-cell cryomodule design (multipacting, BLA for smaller beam pipe, fundamental power coupler, tuner, etc.) after PDR.
- A single bunch instability discovered by EIC team and originating from the small HOM damper requires redesign of the 591 MHz cryomodule. As part of the redesign the team will also improve tuner and multipacting properties.
- Main performance limitations with 591 MHz 1-cell cryomodule are being analyzed and design changes are in progress.
- 197 MHz prototype crab cavity fabrication started. The concept EM and mechanical design is finished.
- Beam screen shields for HSR magnets have been ordered in CD-3A to mitigate heat loads and electron cloud.
- Beam screen materials are stainless steel, copper and amorphous carbon. Carbon contamination is known to be problematic for SRF cavities.

- RF Controls Systems
  - Much of the system is based on RHIC LLRF system, integration is very mature but will need to migrate to EPICS.
  - 197MHz cavities reused from RHIC the 24MHz are modified 28MHz RHIC cavities.
  - 10 common platform chassis have been ordered; one will be sent to TJNAF.
  - Up/down converters for LLRF being developed by TJNAF.
  - Passed FDR for 400kW amps NC RF systems passed PDR FDRs pending.
- Cryogenics
  - The scope of 6.09 cryogenics includes the 3 (or 4) satellite cryogenic plants, the 2K distribution system, and modifications to the existing 4.5K distribution system. Also included in this scope are the cryogenic controls. The cost of the 6.09 cryo scope is $231M.
  - PCR outcomes not in P6 – This results in a cost increase of ~$6M.
    - Beamline Cryotraps
    - Spin Rotator interface
    - Detector cryo interface

- 4K design changes in IR04 (due to lattice changes, space concerns)

Note: The scope of 6.09 does not include removals of segments of the existing RHIC cryogenic distribution system for re-use for EIC.

- The loads are still fluctuating, and the final architecture and capacity of the satellite cryoplant remains undetermined. The functional requirements document for the satellite cryoplants was signed in August 2024, following CD-3A. The IR06 satellite cryoplant loads has been updated with a budgetary load for IR04 for the release of the satellite plant RFP release to reflect the addition of the 3 GeV accelerator and the RCS SRF cavities loads. Additionally, discussions are ongoing regarding the potential consolidation of the satellite cryoplants at IR4 and IR6.
- In general, the cryogenic loads and margins were not presented. However, it has been established that with the addition of the satellite cryogenic plant, the central cryogenic plant will operate near full capacity.
- The connection of the cryomodules to the cryo-distribution system has been reviewed and is now implemented with hard piping, eliminating the use of U-tubes. This design includes two isolation valves, differing from the typical TJNAF configuration.
- Since CD-3A, notable progress has been made on the IR10 satellite cryoplant. The RFP was approved by the DOE on 9/24/2024 and posted on both the SAM and TJNAF solicitation portals the following day. Additionally, the building design for the IR10 satellite cryoplant has advanced. The award for the IR10 satellite cryoplant is scheduled for June 2025, 15 months after CD-3A approval.
- Cryogenics resources increases from 7FTEs in 2024 to 18 FTEs in 2025 and peaks in 2026 with 22 FTEs.
- Seven risks have been identified, none of which are classified as high-level. The listed risks primarily involve potential delays or increased costs. However, technical risks related to fluctuating thermal heat loads and the aging central cryogenic plant have not been addressed.
- The RHIC Central Cryoplant is scheduled for its last run in the summer of 2025 and will remain offline for 5 to 6 years. During this period, maintenance will be necessary to address potential accelerated aging of the system, including rotating equipment, cooling water circuits, and electronics. Significant attention will be required before restarting the RHIC Central Cryoplant, including a renovation exceeding $8 million, which will cover revamping the compressor station, replacing the turbine oil lubrication system, and addressing other end-of-life equipment replacements.
- The path to CD-2 includes:
    - Finalizing Heat Loads

- Finalizing Satellite Cryoplant Architectures
- Finalizing 2K Distribution System (within tunnel geometric constraints)
- Finalizing 4K Distribution System
- Finalizing controls architecture and technical design documents
- Awarding contract for the IR10 satellite plant.
- Obtaining quotes for other Satellite Cryoplants.
- Clarifying the installation and commissioning timeline for all satellite plants.
- Baseline control accounts.

Comments

- The project team has made good progress since the previous Director's review. Several high-level options are being evaluated to reduce risk and cost, and improve schedule and performance. Plans are being developed toward CD-2.
- There are no CD-3B procurements proposed for Global Accelerator Systems.
- Considering the scale of the EIC project, notional funding profiles and various levels of design maturity, the committee feels that the proposed phased/subproject approach to deliver the EIC scope is reasonable. The user community should be engaged in defining early science and for the proposed phased/subproject approach.
- Especially under this phased/subproject approach, boundaries, interfaces and integration plans should be clearly analyzed, defined and reviewed.
- Accelerator system scope is not fixed yet but should be prioritized for the immediate need first while keeping scientific capabilities ensuring design goals and eventually satisfying expectations from the user community. The committee supports ongoing evolutionary efforts to mitigate technical risks.
- Options for the electron injector and the RCS ring should be carefully analyzed and reviewed. Value engineering would be a good way for the baseline development, e.g. recirculation scheme (2 or 3 passes) for the electron injector, lower injection energy into the RCS in phase 1 scope, a separate ring for RCS, etc.
- The on/off project dependencies should be clearly defined and presented in a plenary talk, so it is clear to reviewers.
- Schedule Gantt chart shown in breakout talks should be expanded to show more detail. The current versions are not very useful for reviewers.
- The plan to CD-2 looks daunting for the schedule proposed. The committee encourages the project to achieve a period of stability in requirements and design prior to baselining. There is still a high state of flux in the design of this complex machine.

- There do not appear to be many technical performance risks in the risk registry. It may be beneficial to the project to revisit the risk analysis and consider technical issues.
- During a drill down into the LLRF PDR documentation we found there were several documents that were incomplete and or not signed off. The project has a set of requirements that need to be met for each of the reviews, CDR, PDR, and FDR. In this case the requirements were not met, and the team went ahead with the review. This can inflate the overall design maturity of the project. A check list should be followed such that reviews meet the project requirements. A phased approach can also be taken where predefined design maturities can be validated.
- Leveling out the staff requirements where possible and identifying what additional resources will be available for the project will be beneficial to the successful completion of the scope.

RF Comments

- Given the large scope for the EIC accelerators and especially the RF Systems, the project should consider additional laboratory partners that can bring expertise, capabilities and skilled effort to reduce the burden on BNL and TJNAF staff.
- High-power coupler design and verification for 591 MHz cryomodules is not complete along with issues (multipacting, BLA, new cryomodule design, etc.). Post mitigated risk for the first article 591 MHz and crab cryomodules goes from very high to high. Design changes are in progress and the first article test is delayed by one year – end of FY29. There's still technical and schedule concern.
- CD-3A beam screens with amorphous carbon pose a contamination risk for the HSR, especially for SRF cavities. Technical staff are aware of the risk. The project should strongly support mitigations.
- New SRF systems in the HSR will need to be connected to dirty (by SRF standards) accelerator components. Staff working on SRF are aware of the risk, but the committee feels that project mitigations are not yet sufficient.
- Crab cavities are difficult in several respects including the physical/mechanical design, mechanical tolerance, field stability and feedback. The committee feels this is one of the largest remaining technical risks.
- Final analysis for beam-cavity interactions is in progress with SRF cavities. Thoroughly analyzing the issues and changing the design accordingly, if necessary, will benefit the endeavor.
- Because of the large size of the crab cavity, the mechanical stability is a concern. Diligence will be required in the validation of this design.

- It would be useful to estimate the radiation and secondary particles from IP to determine if this may influence the crab cavity operation.
- Continuing to work on the low-noise LLRF system for the crab cavity should be commended. Additional efforts will ensure cavity performance.

Cryogenic Comments

- The 6.09 Cryo Scope is a complex system valued at $231M. It includes three Satellite Cryoplants with critical connections to the existing RHIC Central Cryoplant, as well as extensive cryogenic distribution infrastructure. This scope warrants a dedicated breakout session.
- The Cryogenic System relies on the RHIC Central Cryoplant. Given the current requirements, the Central Cryoplant is 89% loaded. Any additional load could add risk to the Cryoplant operation.
- While the central cryogenic plant will be shut down for five years, diligence will be needed to retain institutional knowledge and maintain equipment to ensure successful restart of the cryogenic system.
- The plant approved at CD-3A has seen requirement changes post-approval, which concerns the committee. The project should finalize requirements before procurement and avoid further changes. It would be helpful to clarify the contribution of each factor of the procurement process and identify potential improvements to expedite the process.
- The plan to move Satellite Cryoplant Installation and Commissioning from TJNAF to BNL is to be commended. BNL shall ensure sufficient staffing for Installation, Commissioning and Operation.
- Creating another L3 Package to cover Installation and Commissioning at BNL could be beneficial and is worth considering.
- The committee suggests an internal IR10 Cryoplant Interface and Requirements review prior to contract award based on recent changes to the scope.
- The committee suggests the team consider a workshop on global accelerator controls to ensure all interfaces between EIC systems and the injector complex are understood. The interfaces between the injector ADO based controls, the EIC EPICS controls (Both high performance and industrial), and the Cryogenic controls create a set of diverse systems that need to operate as a single system from the operations perspective and must be fully understood.
- Carefully analyzing the cost benefits of using the common platform rather than PLCs for applications where PLCs can meet requirements for speed and control will be beneficial.

Installation Comments

- An integrated installation management team should be established long before installation begins. This team should clarify roles and responsibilities and take ownership of the WPC process. This team should also develop an integrated installation plan as subsystem installation plans evolve. The complexities of tight spaces, 'particle free' installations, and contract labor will need to be carefully thought out, so conflicts are resolved before installation begins.
- Removing the Blue ring from the tunnel addressed an IPR recommendation and risk by providing additional work space in the tunnel. Further improvements related to access for installation and maintenance should be investigated. Lessons learned from the off-project removal of the Blue ring should be captured to inform the installation planning for EIC.
- Once the project scope is defined, a detailed structural analysis of the tunnel should be completed to verify it can accommodate the additional utility infrastructure (cable tray, water pipes, penetrations, etc.).
- If a Davis-Bacon exemption for installation is needed, the request should begin early (at least 1 year before the request approval is needed).
- Dedicated personnel for Work Planning and Control (WPC) is being planned into the P6 installation labor estimates – this should be commended as a best practice.

Recommendations

1. Prior to the January IPR, make all necessary technical decisions to start and expedite the SRF cavity procurement process, especially for the 591-MHz 1-cell cavity.
2. Prior to the January IPR clearly define a design review program with multiple design reviews leading up to the 60% and 90% maturity for example PDR1, 2, 3, FDR x. Define the design maturity and required documentation at each review.
3. Finalize the accelerator systems scope and achieve stability without major changes for six months prior to CD-2.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues bring proactively addressed? ***Mostly yes (see comments).***

2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling? ***Yes.***

3. Are proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are

estimates for proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly? ***Not applicable for Global Accelerator Systems.***

4. Is the project making adequate progress in 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? ***Not entirely (various levels of design maturity).***

6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood? ***Mostly yes (see comments).***

7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Yes.***

8. Is the project ready for CD-3B approval? ***Not applicable. No CD-3B scope for Global Accelerator Systems.***

SC4 – Detector Systems

Findings

- The detector project has significant (and growing) international contributions.
- Critical agreements are not still in place (e.g., with CERN).
- The solenoid is planned as an in-kind contribution. The formal agreement is being prepared.
- Design changes in the machine may impact the detector design and associated infrastructure.
- DIRC bars from BaBar are being re-purposed. A backup plan exists.
- Integration, installation, and infrastructure (III) 3D models are maintained and controlled by the project team.
- The detector team is using 60% maturity for PDRs (expected for CD2 too). The project appears to be using 70%.

Comments

- The sub-committee appreciated the effort the team put in preparation of the review. The project seems to advance well.
    - Talks were very informative and clearly mapped to the charge questions. Their length and breadth could be optimized to focus strictly on the review questions.

- The project is complex. It would be beneficial to provide opportunities for the reviewers to be more informed about the detector before the actual review meetings (e.g., pre-review walkthroughs of the material provided).
- The detector scope is large and requires tight coordination and control by the leading team. The team is doing a great job, and we encourage the project to ensure they have adequate and continuous support.
- The detector relies on a significant fraction of in-kind contributions. It is good for the project but carries complexity and risks. A clear line of responsibility should be maintained.
    - International contracting, enforcing deliverables, possible conflicting priorities, ASME, etc.
- Similarly, the detector depends on off-project deliverables. This also adds complexity and risks.
- Integration and interfaces with the collider, which is in-process of changing design, may have impact of the detector baseline.
    - The detector project complexity is increased because the RCS beamline is adjacent to the solenoid magnet of the detector. This requires additional flux return steel to the magnet which in turn increases the weight significantly. This does necessitate reevaluation of the floor structure. A change in the RCS beamline may alleviate cost and schedule. Finalizing this (and all relevant elements) early is important.
- Breaking of the project in sub-projects may impact seamless integration and interface with detector components and introduces additional risks.
- None of the major findings impacts CD-3A/B. Procurements for CD-3A is progressing well and the need for CD-3B items was well justified.
- Changes (collider design and sub-projects) may impact readiness for CD-2. The detector team is engaged and aware of risks and challenges.
- Simulations were added upon request. They provided more confidence regarding the performance of the detector. It would be beneficial having an extended report capturing the full (global) performance of the detector available before CD-2 (e.g., in the TDR).
- New, very large area silicon detectors carry risks (e.g., Astropix) associated with scalability and availability of technology.
- A plan for bake-out of the beampipe was presented with no obvious show-stopper. Further optimization is being pursued and additional testing is beneficial.
- Expertise and personnel in control of specific critical steps (e.g., chip design verification) is critical and often a limiting factor and has to be taken into account in the schedule.

- Dependence on possibly 'oversubscribed' laboratories for board production of the MPGDs (e.g., CERN) is a risk. It may be mitigated with early procurement.
- New avenues to manufacture AC-LGAD may require several iterations and backup options should remain open.
- Given the balance of NRECs versus wafers costs, additional procurement of ASIC wafers and fabrications (iterations) is encouraged.
- Steel for the endcap are based on one estimate. A second estimate was significantly higher. Additional evaluations of the cost, after further estimates come in, may be needed.
- Results of the first engineering test article of HRPPDs are promising. A second engineering run is encouraged to mitigate risk.

Recommendations

1. Ensure timely and proper finalization of agreements and in-kind contributions. For labs management: provide continued support for contracts and agreements.
2. Complete programs that were developed to retire risks (e.g., research, project engineering development).
    - Contracts should be put in place expeditiously to ensure completion.
    - Evaluation of prototype chips, testing full-chain systems, and thermo-mechanical validation are necessary to proceed with the project.
3. Formalize control and management structure to capture interfaces with accelerator design changes and other sub-system by CD-2.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues bring proactively addressed? ***Yes. CD-3A contracts are being placed. No show-stoppers expected.***
2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling? ***Mostly. The R&D programs were adequately used to mitigate risks for several detector components. In a few areas technical risks are still present.***
3. Are proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are estimates for proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly? ***Yes. Completion of supporting documents is on track for OPA review.***
4. Is the project making adequate progress in 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? ***Yes. Schedule contingency seems good.***

6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood? ***Yes. The management of the detectors relies on maintaining a complex balance with the ePIC collaboration.***
7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Mostly. Some are not yet closed as they are related to CD-2.***
8. Is the project ready for CD-3B approval? ***Yes, but they still need to have final sign-off on drawings and specifications.***

SC5 – Infrastructure

Findings

- The Project is reconfiguring the planned scope delivery into multiple phases and subprojects. The plan for this was not final during the review but the intent is to complete the Infrastructure scope needed for early science in the first phase/subproject and defer some infrastructure needed for an increased science capability to a later phase/subproject. The scope to be deferred was not identified as it is dependent on what science capability will be deferred which is TBD
- The Project is assessing trade-offs for an in-tunnel RCS vs an external RCS. The external RCS approach could have substantial cost impact on Infrastructure budget. Cost is TBD.
- The Project is assessing trade-offs for electron injection method which will have cost impacts on Infrastructure
- The Project intends to make a final decision on method (and infrastructure needed) to achieve electron injection and the approach for the RCS by January 2025. This portion of Infrastructure design is not yet included in the A/E scope and hi-confidence estimates do not exist for this scope yet
- The A/E has completed 30% final design and is working toward the submittal of 60% final design package in December 2024 with overall design completion (less Injection and RCS scope) scheduled for June 2026. The A/E deliverables have been as scheduled.
- Current estimates provided by the A/E and budgeted in P6 do not include all scope expected to be required and A/E estimates for known scope are running higher than what is budgeted in P6.

- The Project estimates final design of the Injection and RCS scope (currently on hold) can be completed in 12-15 months after A/E contract modification.
- NY state funding eventually totaling $100M is now available (through a formal release process) and is planned to be utilized for construction starting in mid-2025. It must be expensed by 2029 and is not constrained by the CD-3 authorization process.
- The project plans to execute 4 construction packages: Site Prep (NYS funds); NYS Building Construction (NYS funds); DOE Buildings, Power and Mechanical (DOE funds); Electrical Distribution (DOE funds).
- The current budgeted cost in P6 for Infrastructure is $381M (including $100M NYS). A separate risk-based contingency for Infrastructure was not identified. Project contingency was identified as 35% on work to go and 10% on level of effort work yielding ~28.7% overall.
- Costs not included in the current estimates are: Crab Cavity Buildings; RCS and added Injection Structures; Beam Position Monitoring Structures; Kicker bldg.; Low Energy Cooler facilities.
- The current schedule in P6 does not reflect the current scope or phasing/subproject plan and does not include a current breakdown of activities, durations and dependencies required for readiness for CD-2.
- The Infrastructure CD-3A scope is ready for award and will address a substantial portion of the MWBE (Minority and Women-Owned Business Enterprise) award target required by the NYS funding agreement.
- The Off-Project Dependency List includes items critical to Infrastructure scope including tunnel fire protection upgrades, water utility service for the site, and site electrical power upgrades.
- The Davis-Bacon Determination for the project has not been completed.
- The Infrastructure Team plans to contract a CM Advisor (CMa) to provide preconstruction services and support construction oversight. They would also provide independent estimates to assist with baseline development for CD-2.

Comments

- The Infrastructure Team is well managed, properly staffed and is making excellent design progress for the scope that has been identified and incorporated in the project.
- The plan for 4 construction packages and initiation of NYS funded construction in FY25 is good and enables a favorable ramp up to a construction oversight posture for the Project. An

internal 'CD-3-like' construction readiness review should be implemented prior to construction start.

- The Infrastructure team is commended for taking a proactive approach to resolving questions regarding the current machine design as it relates to existing system designs/capacities (e.g. rail/floor loading vs. new detector designs).
- There have been substantial accelerator driven design changes requiring additional facilities that are not yet incorporated in the design and budget. A major design change for the RCS and Injection systems is planned and there are other support buildings known to be needed but currently not fully implemented in the scope and design. These changes need to be decided, approved by the CCB and incorporated in the project very soon to enable A/E design to start and to meet project goals for timely CD-2.
- There is a substantial budget variance for known and likely needed scope not yet included in P6, and the A/E estimate variance vs. current P6 budget for approved scope. This variance will require timely resolution for readiness for CD-2.
- The current schedule in P6 does not reflect the current scope or phasing/subproject plan and does not include a current breakdown of activities, durations and dependencies required for readiness for CD-2. Design maturity targets for scope not currently contracted with the A/E will need to be established. Both are needed to have an implementable plan to achieve CD-2.
- A much higher degree of cost certainty is required for readiness for CD-2. Current estimates must be upgraded to include all scope. The plan to bring a CM advisor on-board to provide independent estimate support is good and should be expedited. A risk-based contingency estimate should be developed to support the estimate.
- The Infrastructure items in the Risk Register should be reviewed to insure they are sufficiently granular to enable a risk based contingency estimate. Infrastructure related items on the Off-Project Dependency list should be individually included in the Risk Register so they can be tracked, and their relative cost risk determined.
- The level of confidence resulting from the design definition has not been included in the estimate. As the estimate is at Class 3, the high end of the range could account for 30% in estimate delta.
- The Infrastructure Team Construction Project Manager position has been filled and is commended for engaging in construction oversight practices with experienced BNL facilities construction staff.
- The Phasing/Subproject plan needs further definition to enable development of a plan to achieve CD-2.

- The CD-3A procurement of Unit Substations is progressing well. Since ~24 additional units will eventually need to be purchased by the project, they are a good candidate for a future LLP if sufficient funding is available.
- The Davis-Bacon determination should be completed for the project to assure that interface points in construction packages are properly aligned with the method of execution and to inform decisions on method of execution as planning for CD-2 progresses.

Recommendations

1. Expedite award of an A/E contract modification to provide design and estimating support to enable earliest resolution of decisions and technical requirements for the injection and RCS design.
2. Prior to the OPA review, prepare a design plan for soon to be incorporated scope to align with project goals for CD-2.
3. Prior to the OPA review, quantify budget variance (approximate range) from current P6 and develop preliminary plan for resolution.
4. Prior to the start of NYS construction, conduct an internal Construction Readiness Review.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues being proactively addressed? ***Yes, excellent work on approved scope.***

2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling? ***Not applicable for Infrastructure Systems.***

3. Are proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are estimates for proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly? ***There are no CD-3B procurements proposed for Infrastructure Systems.***

4. Is the project making adequate progress in 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? ***Yes, for approved scope/No - where RCS/SRF decisions are needed.***

6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood? ***Yes- excellent team and progress on CD-3A - but see comments regarding Risks and CD-2.***

7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Yes.***
8. Is the project ready for CD-3B approval? ***Yes.***

SC6 - Cost and Schedule

Findings

- CD-0 approved Dec-2019 and CD-1 approved Jun-2021. Proposed CD-2/3C Q2 FY26.
- Total current Point Estimate $2.949M including $659M contingency, 5% above CD-1 top range. In-kind cash goals of $166M not included.
- CD-3A Long Lead procurements (LLP) - $90M were approved in March 2024. The first contract award for the Direct Wind Magnets Superconducting Strand was awarded in October 2024. Tracking of 16 LLP items indicate 56% are on track.
    - Two PCRs have been executed since CD-3A baseline was set May 1, 2024, one Admin and one Level 2 with contingency draw of $4.4M.
- CD-3B LLP - $49M with contingency planned for approval in March 2025. LLP candidates reduce risk and support project tracking to CD-2 target date. Procurements are split between the Accelerator (5 items) and Detector (6 items) and remains independent of technical finalization in the accelerator.
    - All FDRs, requirements and interfaces for the proposed CD-3B scope are complete.
- The Project Controls team presented a comprehensive list of items and a timeline outlining a path to prepare for CD-2.
- WBS will be restructured to streamline reporting and management in concert with exploration of phased execution.
- To mitigate risks relative to a prolonged construction schedule and long dark times, a two phased approach is in development. Phasing sub-project costs are $2.8B for phase 1 and $.5-.7B for Phase 2. Goals and requirements have been developed for phase inclusion.
- Independent of phasing, significant project efforts focused on accelerator performance and final changes to the technical baseline.
- Off-project Scope and dependencies are substantial and integral for EIC deliverable success with needs identified in the areas of Accelerator & Infrastructure, Detector and Host Laboratory.

- Cost contingency currently based on top-down approach with 35% on non-LOE and 10% on LOE. This yielded 28.7% total project contingency. Schedule contingency is 24 months. Calculation via Monte Carlo analysis for full project scope is planned for 2025.
- Project has 181 active risks and 9 opportunities.
- 23 DOE recommendations remain open of 138 total, 115 closed.
- Associate TJNAF PM and EIC Project Support Division Director will be retiring soon.
- CD-3A/B EV scope is limited to the procurement and delivery activities only. Associated design was not baselined due to final design completion.
- Drilldowns were performed on CD-3B scope from WBS elements 6.04.02.01, 6.04.03.01, 6.10.05.01 and 6.10.08. Scope represented deliverables to be executed by BNL and TJNAF.
- Exchange rates are determined at the time of PCR execution. Project utilizes foreign exchange rate calculator as the source reference.
- Cumulative project funding to date is $490M. DOE has provided $392M inclusive of $138M in IRA funds. A $100M New York State grant for EIC buildings awarded in Feb 2024.
- The FY25 funding plan is $150M relative to developing budget scenarios with a Presidential request of $113M, House at $128M and the Senate with $138M.
- FY26 funding target was $300M for version 4.2 reference funding profile and includes project transitions for EIC construction, RHIC operations conclusion, and reduced RHIC operations funding for the injector complex and the removal/repurpose of equipment.
- The Project Controls team presented a comprehensive list of items and a timeline outlining a path to prepare for CD-2.

Comments

- The EIC project support division and project controls team is very strong. They have strong processes and an impressive tool suite for planning and performance reporting.
- CD-3B CAMs were well prepared for drill-down sessions and displayed solid basis for cost estimates and schedule duration.
- With regard to preparation for CD-2, the project plan is dependent on critical inputs that are still missing or in flux:
    - External dependencies – the substantial and varied portfolio of projects that EIC is dependent on are not yet integrated into the schedule. Tying these external constraints into the schedule and ensuring that the project stays under annual funding caps will be an iterative process.

  - Subproject strategy - Work required to pivot to subprojects will be substantial on a project of this magnitude - impacting cost, schedule, risk/contingency approach, project docs, tools, etc…
  - Accelerator scope - RCS and injector changes are substantial. A baseline cannot be established until this scope is finalized and associated schedule, estimate, risks, and project documents are all updated.

- Outside of 3A and 3B, the project is still relying on a top-down approach to contingency that results in 28.7% contingency for the total project. It is understood that risks and uncertainties will be refined ahead of CD-2, but current risk register inputs and project context make clear that contingency, as presented, is inadequate.
- The EIC project has known technical risk, but also significant systemic risks related to external dependencies, in-kind contributions, multiple funding sources, multinational collaboration, and brownfield installation to name a few. The team should be careful not to understate these risks at this early stage of the project.
- The timeline to CD-2 should consider time for properly assessing cost estimate and schedule uncertainty, risk impacts and probabilities, and risk-to-schedule mapping for Monte Carlo simulation after the base estimate and schedule have stabilized.
- 3A scope is progressing but with many procurement delays (36 at JLab) driven primarily by technical changes.
- In response to anticipated FY25 funding budget shortfall, project is targeting the Senate mark ($138M) for what-if analysis. The House mark may prove more realistic.
- A subproject and phasing strategy is being considered but final decisions are not yet made. Aligning all project artifacts with this strategy will be a heavy lift. See PM section (SC7) for applicable recommendations.
- Project has begun to deploy an apportioned earned value technique for technical rep support. Application is not consistently applied for the CD-3A scope. Project should consider time tracking as a feedback loop to validate this planning detail.
- Include status on open recommendations in presentations as some have remained open for multiple reviews.
- The path to CD-2 baseline by Jan 2026 is aggressive and is based on assumption that accelerator scope changes and subproject strategy are final by end of CY24. It also assumes clarity on assumptions for external dependencies early in Q1 CY25. Rushing these critical decisions and setting a CD-2 baseline too soon may not be advantageous in the long run.

Recommendations

1. Clearly identify/define off-project dependencies and fully integrate these dependencies into project schedule prior to baseline.
2. Proceed with 3B.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues bring proactively addressed? ***Yes.***

4. Is the project making adequate progress in 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? ***No, progress is evident but is impeded by lack of definition on project external dependencies and subproject strategy. As a result, the scope remains in flux and the TPC remains unknown. Contingency is inadequate given current risks and uncertainties.***

6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood? ***Yes (see comment on contingency).***

7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Progressing. There are 23 open recommendations, some of which are particularly aged (2021). Many have a CD-2/3 completion targets so they are not required to be complete but not yet "satisfactorily addressed".***

8. Is the project ready for CD-3B approval? ***Yes.***

SC7 - Project Management

Findings

- In order to accomplish EIC, the complete picture includes: the DOE-funded EIC Project, In-Kind Contributions from International Partners, Scope funded by New York State, and a number of external dependencies.
- There are a significant number of external dependencies (aka off-project), from R&R in the RHIC tunnel, maintenance of the existing Accelerator (AGS/RHIC) complex, lab infrastructure, assembly and testing space, Detector assembly space, and 'Host Lab' duties. A series of reviews were held in late 2024 to assess the requirements and state of the work.
- BNL Laboratory management reported that they are close to naming an individual to lead the EIC external dependency program.

- RHIC operations is expected to conclude at the end of calendar year 2025. The funding and staff made available by this are required for EIC to execute the proposed plan.
- The EIC project is anticipating receiving $12M-$37M less funding than outlined in their annual funding plan. Funding constraints are driving the need to divide project scope into phases and sub-projects. The rough concept, without details, was presented by the project team.
- During the review, the project team discussed changes to the project scope of work, mostly related to technical decisions associated with the electron injector, RCS, and hadron cooling. The project's Cost Book documents the estimates associated with the default plan (400 MeV linac, Strong Hadron Cooling). Costs of the other options were presented but are not in the P6 schedule or documentation. The funding uncertainties and remaining technical decisions influence the discussion of subprojects.
- A cost-weighted design maturity (CWDM) is determined based on design review completion and associated cost. The CWDM percentage for the total project at the end of August was ~45%. The project plans to be at 70% by CD-2.
- There are 11 iCRADAs in draft state for the detector and accelerator in-kind contributions. The project is anticipating a 6-month processing time with a proof-of-concept test coming in the next month to begin benchmarking.
- Eight out of the eight Final Design Reviews have been conducted for the proposed CD-3B scope.
- One out of the 50 (13 BNL, 37 TJNAF) procurements have been placed for the baselined CD-3A scope. 40 (4 BNL, 36 TJNAF) of the procurements are behind the original plan for award.
- There are 1,129 procurements planned on the project with a peak appearing in FY2027 at 460 procurements (with 219 in January 2027 alone). That is approaching two procurement awards per day for a full year.
- Current BNL procurement cycle times range from ~5 months (<$2M) to >2 years (>$100M).
- Staffing plans for the project, taking into account the needs and the labor pools at both BNL and TJNAF, were presented. Anticipated changes to key staff roles were noted.
- A framework exists for actively engaging international partners, participating institutions, and science user communities via steering committees; collaborations; boards; and steering groups.
- A Code of Record has been developed for the Project.
- The Project has developed the required DOE O 413 ESH&Q documents required for CD-2.

  - Environmental Assessment and Finding of No Significant Impact
  - Quality Assurance Plan (QAP)
  - Integrated Safety Management Plan (ISMP)
  - Hazard Assessment Report (HAR)
  - Preliminary Fire Analysis Report (PFAR)

- The Project is actively developing and applying for the environmental permits necessary for infrastructure construction.
- The Project is using a requirements database, VISURE, to manage system requirements.
- ESH&Q risks have been identified and are tracked in the Project Risk Registry.
- A plan for a successful Accelerator Readiness Review (ARR) is being developed.
- Each Partner Laboratory have Traveler and Lessons Learned systems.
- Memorandum of Agreements (MOAs) on Pressure Safety and Non-NRTL Equipment have been developed and signed by the Partner Laboratories.
- The Project has experienced ES&H and QA managers. A staffing plan for ESH&Q support has been developed.

Comments

- The project team should be commended for evaluating funding constraints proactively and attempting to get to early science as quickly as possible.
- The timeline presented for achieving CD-2 seems aggressive and optimistic given the decisions yet to be made and the number of variables at play. Outside of the funding limitations causing changes to approach (subprojects), there are still elements such as external dependencies (off project), and changes to technical approach that need to be appropriately addressed or a complete picture of what a successful performance baseline looks like is not possible.
- Since the off-project R&R scope is rapidly approaching, it urgently needs to be assigned to a project manager who can talk about the cost estimates, schedule plans, and progress at the January 2025 IPR review.
- The balance of off-project dependency scope needs to be fully defined with viable funding paths and a method for continually monitoring its progress in place, before the EIC project is baselined. This has been a stated need for a number of years now and some funding paths may already be too late to pursue.
- The concept of EIC sub-projects and phases needs to be discussed more definitively at the upcoming January 2025 IPR, but the project should not try to re-plan the cost and schedule

details or modify the existing WBS prior to the review. This would be premature and jeopardize CD-3B.

- As presented, the relationship between Phase 1, Phase 2, sub-projects, possible KPPs, and machine capabilities at 'First Science' are not clear. The project team should consider developing a visual – such as a block diagram – to help orient reviewers to the proposed plan(s) for the IPR.
- The CD-3A scope is progressing with some delays but the project appears to be learning from this initial execution. The proposed CD-3B scope appears to be well developed and ready for approval.
- Procurements have the ability to completely halt the progress of this project. The project should continue to use Procurement Liaison Engineers and encourage lesson learned/information sharing between these individuals on a regular basis. This should include monitoring planned procurement throughput times for accuracy.
- Based on recent lessons learned from projects within the DOE SC complex, baselining at 70% design maturity may be too low. This value is further concerning since the technical maturity measurement could be overstated due to the mechanism used for obtaining PDR credit (example: recent PDR for LLRF).
- The Associate Project Manager for TJNAF will be retiring soon. Given the importance of this position to the success of the integrated BNL/TJNAF management organization, the EIC Project Director needs to be involved in the selection of the replacement.
- The Project's Quality Assurance Plan (QAP) is high level and does not reference documents mentioned in the Plan by the document number. It makes it difficult for the reader to cross-reference the documents mentioned in the Plan. Adding the document reference numbers would prevent any confusion for users of the QAP.
- The RHIC facility will continue to be managed under DOE O 420.2D, *Safety of Accelerators*, as the facility is prepared to transition to the EIC Project. A new Accelerator Safety Envelope (ASE) and Safety Assessment Document (SAD) will be developed for the EIC.
- Each Partner Laboratory use its own lessons learned systems, which are not integrated. The respective QA managers determine which lessons learned are relevant and should be shared with the Partner Laboratory. An integrated system would enhance the sharing of Lessons Learned and is encouraged.
- Each Partner Laboratory have separate Traveler Systems. The Project QA managers are currently developing a process to transfer the necessary information generated by TJNAF to the EIC Project and this should be encouraged.
- The EIC eTraveler and Nonconformance Reporting (NCR) module does not integrate with BNL's Integrated Operational Performance System (IOPS) as required by BNL's SBMS

Subject Area, *Events/Issues Management*. Authorization is needed if the software will not be integrated with IOPS.

- Minimal information was provided on the Project's radiological hazards and controls. Information should be available on estimated dose to workers, the public, and environment. Radiological evaluations need to be completed to inform design decisions. The Project intends to bring on an additional Monte Carlo expert.
- The Project believes environmental hazards, such as asbestos, PCBs and lead, do not exist in the RHIC tunnel because of the age of the facility.
- The Project has a draft Construction Safety and Health Plan (CSHP). BNL has a SBMS Subject Area, *Work Planning and Control*, that includes a Health and Safety Plan for Construction Contractors that is mandatory for projects at the Laboratory. As such a Project CSHP may be redundant.
- The Project has an ISM Plan and HAR. The documents contain some language that is outdated and not consistent with SBMS. For example, the ISM Plan uses outdated terminology such as PHA (Phase Hazard Analysis) or JRA (Job Risk Assessment), both terms have been replaced with JHA (Job Hazard Analysis). The HAR Section 3.1 does not describe the approval of non-NRTL equipment completely and correctly. HAR 3.4 Cryogenics designates a Laboratory committee incorrectly as an Authority Having Jurisdiction (AHJ).

Recommendations for Lab Management

1. Act urgently on establishing a single responsible person for the ownership and execution of the off-project dependency scope elements. This should be completed by the end of November 2024.
2. Assign a project manager for the R&R project who will define and present the R&R scope at the January 2025 IPR.
3. Perform pre-baseline review(s) of the dependency scope before CD-2.

Recommendations for EIC Project

1. Expedite initial radiological evaluations including calculations for Project structures and activities by the end of FY 2025-Q3.
2. Evaluate whether the Project should use BNL's Health and Safety Plan for Construction Contractors that is mandatory for Laboratory projects rather than creating a separate Project Construction and Safety and Health Plan by the end of FY 2025-Q1.
3. Obtain authorization for exemption from reporting NCRs in BNL's IOPS by the end of FY 2025-Q2.

4. Work with BNL subject matter experts to update the ISM Plan and HAR by the end of FY 2025-Q2.
5. Proceed with detailing the subproject approach but without jeopardizing CD-3A or CD-3B baselines and project documentation for the January 2025 IPR.
6. Provide sufficient time for the pending technical decisions to account for design maturity/review, community support, and credible estimates to be included within the baseline plan.
7. Proceed with CD-3B.

Response to Assigned Charge Questions

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues bring proactively addressed? ***Yes. CD-3A work is being effectively executed, although procurements are taking a long time to get through the system. Technical issues, overall, are being addressed but there are critical issues that will need to be addressed very soon so that other work can proceed.***

2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling? ***N/A.***

3. Are proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are estimates for proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly? ***N/A.***

4. Is the project making adequate progress in 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? ***No. While substantial progress has been made by the project team in development of the performance baseline, due to external dependencies, technical changes, and subproject strategy uncertainty it is too difficult to evaluate at this time.***

5. Are ES&H and QA properly addressed given the project's current stage of development? ***Yes.***

6. Is the project being properly managed? Yes. Are risks being effectively managed? **Yes.** Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? ***Yes, for CD-3A and CD-3B but not for the performance baseline due to lack of ownership on the dependency scope, which needs to be understood prior to the CD-2.*** Are roles and responsibilities documented and understood? ***Yes, for those that are on the project. For those outside of the project, no.***

7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews? ***Some items are taking far longer than they should to complete. For example, the external dependency scope has been a recommendation since January 2021 CD-1 IPR and every year since.***

8. Is the project ready for CD-3B approval? ***Yes.***

Appendix 1 – EIC CD-3B Director's Review Committee Charge

Electron-Ion Collider

Brookhaven National Laboratory · Jefferson Lab · U.S. DEPARTMENT OF ENERGY Office of Science

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Upton, NY 11973-5000
Phone 631.344.2719
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managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

date: *July 29th, 2024*

to: *Mark Reichanadter, Retired SLAC & Patty McBride, FNAL*

from: *Jim Yeck, EIC Project Director/Associate Laboratory Director*

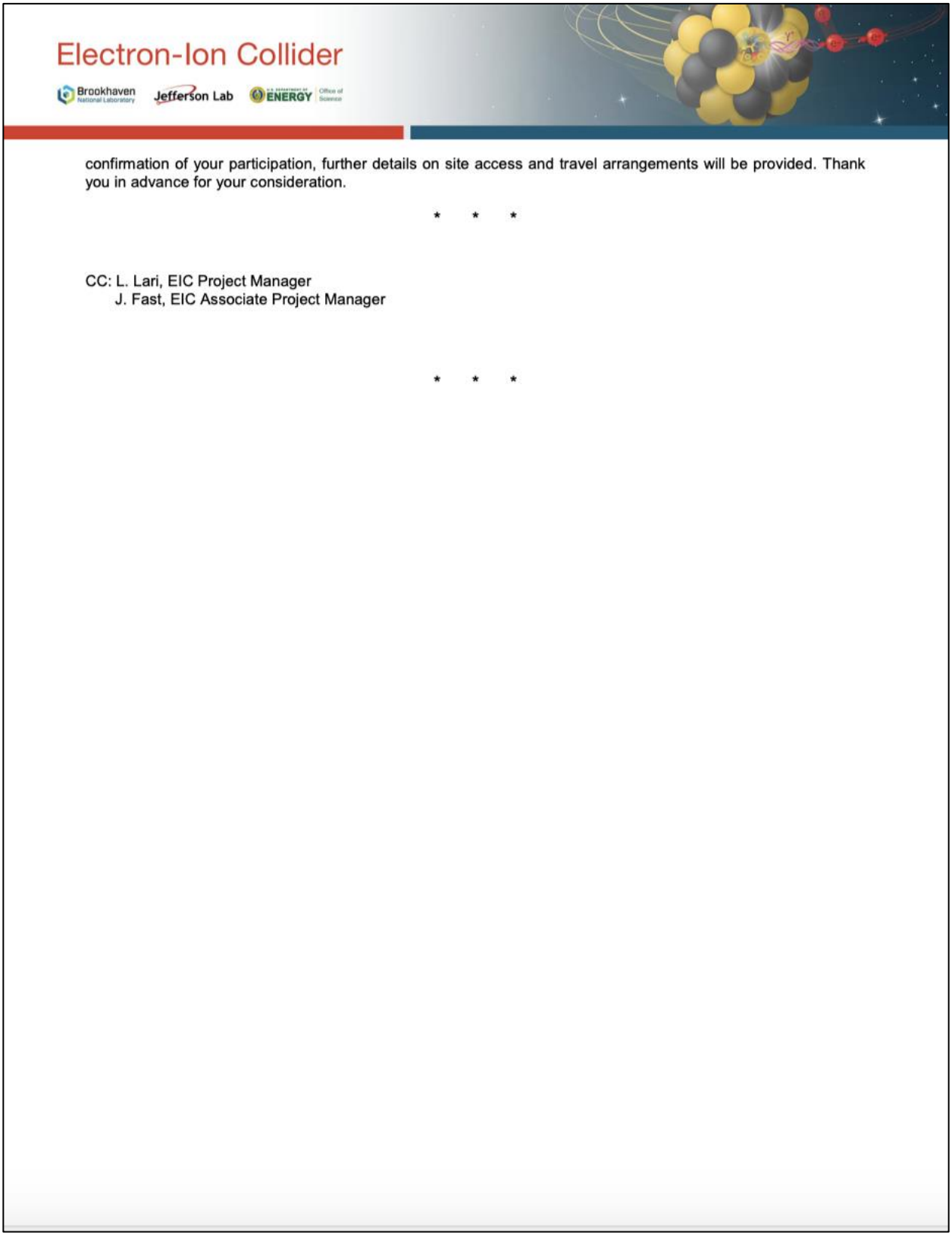
subject: *Charge for the CD-3B/Status Director's Review of the Electron-Ion Collider (EIC) Project*

I request your assistance with a Director's Review of the Electron-Ion Collider Project at Brookhaven National Laboratory and serving as co-chair on October 22-24, 2024. The primary purpose of this review is to assess the overall status of the EIC Project and to determine if the Project is adequately prepared to request Critical Decision-3B (CD-3B) "Approve Long-Lead Procurement (LLP)." The recommendations from this review will help the project prepare for the Department of Energy (DOE) Office of Science (SC) Independent Project Review (IPR) on January 7-9, 2025.

The EIC Project obtained DOE SC approval to execute a CD-3A LLP package of approximately $90M in March 2024. Approval for CD-1 "Approve Alternate Selection and Cost Range" was secured in June 2021. The project is planning to request DOE SC approval for CD-3B in the Spring of 2025 and, depending on annual funding, approval of a project baseline at the end of the calendar year 2025, when RHIC concludes operations. The EIC will enable scientists to tackle several key scientific questions in fundamental physics such as determining the 3D structure of protons and nuclei, searching for gluon-saturated matter, and solving the mystery of the proton spin. The committee is asked to respond to the following charge questions:

1. Is the project team effectively executing the current work, including the CD-3A performance baseline, and are technical issues being proactively addressed?
2. Are R&D and design efforts mitigating technical risks, particularly in strong hadron cooling?
3. Are the proposed CD-3B long-lead procurements appropriate, and do they support project risk mitigation? Have the proposed CD-3B long-lead procurements completed final designs? Are estimates for the proposed CD-3B long-lead procurements appropriate? Can these procurements be tracked properly?
4. Is the project making adequate progress in 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?
5. Are ES&H and QA properly addressed given the project's current stage of development?
6. Is the project being properly managed? Are risks being effectively managed? Is a management team in place to successfully execute the project including the CD-3A scope, the proposed CD-3B scope, and the preparation of the CD-2 performance baseline? Are roles and responsibilities documented and understood?
7. Has the project satisfactorily addressed recommendations from previous DOE SC reviews?
8. Is the project ready for CD-3B approval?

The EIC Team will provide background materials to the committee by October 9th and a pre-review meeting will be scheduled to provide an overview of the project, documentation, and charge questions. The committee shall present a closeout on the last day of the review and a draft written report shall be provided to the EIC Project Director within 30 days. All travel costs, including per diem, while attending the review will be covered and arranged by BNL. Upon



confirmation of your participation, further details on site access and travel arrangements will be provided. Thank you in advance for your consideration.

* * *

CC: L. Lari, EIC Project Manager
J. Fast, EIC Associate Project Manager

* * *

Appendix 2 – EIC CD-3B Director's Review Committee

CD-3B/Status Director's Review
Electron Ion Collider (EIC) Project at BNL
October 22-24, 2024

Mark Reichanadter, Co-Chairperson, Retired SLAC
Patricia McBride, Co-Chairperson, FNAL

SC1
Injectors
(WBS 6.03, Hadron Injectors)

* Timur Shaftan, BNL
Kathy Harkay, ANL
Eliana Gianfelice-Wendt, FNAL
James Safranek, SLAC
John Schmerge, SLAC

POC- Sergei Nagaitsev
Admin- Dana Macciola

SC2
Collider
(WBS 6.02, 6.04, 6.05, 6.06)

* Alexander Valishev, FNAL
Wolfram Fischer, BNL
Steve Gourlay, FNAL
Georg Hoffstaetter, Cornell
John Seeman, SLAC

POC- Christoph Montag
Admin-Christina Blas

SC3
Global Accelerator Systems
(WBS 6.07, 6.08 & 6.09)

* Sang-Ho Kim, ORNL
Joe Delong, SLAC
Eric Fauve, SLAC
Mike Kelly, ANL
Mathew Howell, ORNL
Jerry Leibfritz, FNAL
Slava Yakovlev, FNAL

POC- Jim Fast
Admin- Tammy Dellaiacono
Admin- Christine Fragapane

SC4
Detector Systems
(WBS 6.10)

* Gabriella Carini, BNL
Anna Macchiolo, CMS/Zurich
Tim Whitlatch, JLAB

POCs-Rolf Ent & Elke Aschenauer
Admin- Anna Mendez

SC5
Infrastructure
(WBS 6.11)

* Marty Fallier, BNL (ret)
Steve Dixon, FNAL
Canon Cheung, SLAC
Keith Orr, LANL

POC- Charles Folz
Admin- Kristine Schoefer

SC6
Cost and Schedule

* Kathy Bailey, ORNL
Jared Spradling, ORNL
Lorri Stapleton, FNAL
Kathryn Southworth, ORNL

POCs- Cathy Lavelle & Kelly Krug
Admin- Donna Rassner

SC7
Project Management
(WBS 6.01, 6.12, Off-Project)

* Jennifer Fortner, BNL
Mario Cubillo, BNL
Paul Derwent, FNAL
Diane Hatton, BNL (ret)
Crystal Schrof, ORNL (ret)

POC- Luisella Lari
Admin- Mary Ellen Thelen

OBSERVERS

Robert Caradonna, BHSO, EIC FPD
Craig Ferguson, TJSO
Bryan Foley, TJSO
Romayne Howard-McKellar, BHSO
Ivan Graff, ONP
Wayne, Skinner, TJSO

LEGEND

SC Subcommittee
* Chairperson
ITA Remote Participant

Committee Count (excluding observers, POCs, & admins): 35