Report of the Thomas Jefferson National Accelerator Facility

Accelerator Advisory Committee

March 8-10, 2023

Committee members:

Oliver Brüning (CERN), Sarah Cousineau (ORNL), Stephen Holmes (FNAL ret.), Kevin Jones (ESS, ORNL ret.), John Seeman (SLAC) (chair), Akira Yamamoto (KEK, CERN), Yoshi Yamazaki (MSU), and Marion White (ANL). Richard Milner (MIT) tendered his regrets.

Executive overview:

The JLab Accelerator Advisory Committee (JLAAC) held a hybrid in-person/virtual review March 8-10, 2023. The review covered 29 major topics.

For this review, five "Charge Questions" from JLab were presented to the AAC committee to assess. In addition, 29 technical presentations covering the breath of the accelerator program were given. The AAC addressed, below, the charge questions and has made detailed comments and recommendations on the specific technical talks.

The committee wishes to thank the Jefferson Laboratory staff for interesting presentations, in-depth technical discussions, and helpful review logistics.

The JLAAC review agenda for this March 2023 meeting is shown in Appendix A.

Responses to the Charge Questions:

1) CQ1: *Please assess progress in 12 GeV CEBAF Operations generally, and specifically comment on our plan for reaching the appropriate energy using a combination of CM refurbishment, C75 program, as well as plasma processing in tunnel. Also comment on the development of future RF power options, such as SSA and magnetrons.*

The CEBAF goal remains to provide at least 30 weeks of operation annually, at an available energy of 12 GeV and with reliability against schedule of at least 80%. Work toward these goals is being organized and executed in accordance with the CEBAF Performance Plan (CPP) Project Description (2020-10-07). The CPP contains two major components: one aimed at increasing the energy reach and the other aimed at improved reliability. The reliability is dependent on both the energy and the total beam power and is reduced when running at higher beam power.

FY2022 operation delivered almost 33 weeks of scheduled operation and 27 weeks of a 4-hall physics program in two segments with overall operational reliability of 76.5%. The segments were separated by a 3.5-month shutdown (SAD). During the SAD, in addition to regular maintenance activities, two C20 cryomodules were removed and replaced with C75 and C50 cryomodules respectively. One C100 cryomodule was replaced with a similar unit with better energy gain. Overall energy gain resulting from these replacements was ~68 MeV in the North linac and ~25 MeV in the South linac. At the beginning of FY2022 the average linac energy gain was 910 MeV, and at the end of FY2022 it was 1047 MeV.

FY2023 operation is well underway, and 33 weeks of 4-hall operation are planned with an energy gain of 1047 MeV/linac. Reliability year-to-date is 73.0%. CEBAF is now authorized to operate at a maximum beam power of 1.1 MW, and efforts are being made to increase the overall beam power delivered primarily to Halls A and C to support efficient experimental performance. Operation at higher power (800-900 kW) stresses both systems and staff and may affect reliability. A 4-month SAD is planned starting in mid-March 2023. Key activities include the injector phase 2 upgrade, booster replacement, installation of two re-built C100 cryomodules (one replacement), and newly-developed in-situ plasma processing of three C100 cryomodules in the South linac. The results of plasma processing for individual cavity strings and cryomodules can vary considerably. This technique, discussed in more detail later, is essential to building and maintaining energy margin in the absence of a spare C100 cryomodule. Operation for more than 30 weeks a year limits cryomodule replacements to two per SAD, rather than the four planned in the CPP Project Description. The overall energy gain anticipated is ~98 MeV in the North linac and ~52 MeV in the South linac. These gains would permit operation at ~12 GeV without margin.

CEBAF reliability is dominated by long down-times arising from three principal sources: RF, Magnets, and Beam Transport. For FY2022 and FY2023 these account for 70-80% of the down time. Long down times are roughly equally distributed into two categories: 30 minutes to 4 hours, and > 4 hours. Reliability is also affected by fast beam interruptions averaging 11.6 per hour in FY2022 and 12.6 per hour in FY2023.

Solid State Amplifier (SSA) alternatives to klystrons are becoming cost-competitive, and present a potential path forward to replace klystrons as RF energy sources for the CEBAF linacs. The JLAB team has considerable experience in deploying and operating such sources. Initial studies are underway to develop a workable solution given the physical constraints of the RF infrastructure locations. Magnetrons offer higher efficiency options to drive the CEBAF linac, but additional investment is required along with extensive testing to fully characterize long-term stability and operational performance before this could be considered an option to replace the present klystron power sources.

The CPP notes that no further expenditures are required for critical spares. The reliability focus centers on klystron procurement and rebuilding together with investments to address immediate needs and obsolescence. These investments are modest ($2.7M), and only partially address the systems that principally contribute to down time. For energy reach, the CPP identifies the spare C100 cryomodule as important to maintaining energy margin for 12 GeV operation.

The CPP Project Description Document does not incorporate recent developments such as plasma processing and evaluation of SSA and magnetron options. Plasma processing will become an important part of the energy reach management program. It also does not address the increase in run-time and the resulting effects on shutdown activity planning.

Recommendations:
R1: Revise the CPP Project Description Document on an annual basis to ensure that it incorporates new knowledge, capabilities, and facility performance to optimize achieving and maintaining 12 GeV operation with expected reliability.

R2: Incorporate an updated risk register into the CPP Project Description Document to ensure alignment between identified performance improvement opportunities and activity schedules and budgets.

2) CQ2: *Please assess and comment on JLab EIC activities and progress.*

Overall, JLab is well set up within the EIC organization with 2 Level II managers and several deputy Level II managers. The engineering activities around the cryogenic system, magnets and SRF designs are well defined and on a good track for the required EIC planning towards CD-3a and CD2.

The presented progress for the design of the cryogenic system, the magnets, and the SRF systems was impressive and assuring.

However, staffing and filling open positions seems to be challenging in some areas at JLab, e.g. the SRF activities. It was not clear from the presentations if these staffing problems directly affect Jlab's contributions to the EIC.

Some EIC related activities require infrastructure upgrades at JLab, e.g. for the SRF activities. While these upgrades can in principle be launched with EIC funds, the upgrades can still be limited or challenged in some cases by the present space limitations at the JLab facilities.

The AAC learned during the review that local Laboratory Engineering and Safety standards are applied for the design and production of equipment at JLab and BNL. These standards can, in principle, vary between the two laboratories.

Some EIC components have a rather small series production quantity, e.g. the crab cavities. This might leave industrial partners only little room or time for gaining experience when the series production of components starts in industry. This might lead to non-conformities and production faults during the series production which can be difficult to accommodate in a small series production.

Some EIC components under the JLab responsibility might be particularly exposed to recent market pressures, market volatility, and price fluctuations, e.g. the cryogenic system and its distribution lines. Tendering and production of these components might therefore have high risks for higher costs and schedule delays. It might therefore be challenging to obtain a sufficient number of companies to submit reasonable offers for the final tendering.

The hadron beam cooling proposals are still on a relatively conceptual design stage, given the overall EIC project status and planning. Progress and design validations over the coming year are critical for a successful implementation in the EIC.

Recommendations:
R3: Assure that the engineering and safety standards at BNL and JLab are well aligned in a documented agreement and that the production of components for the EIC at JLab are defined in such a way that the components can be installed at BNL without additional approval procedures.

R4: For the industrial production of small quantity items in industry, it will be advantageous to have the industrial partner already on board for the prototype development and testing at the partner laboratory. e.g. crab cavity production. Establish for such items contacts with potential industry partners already during the prototyping stage.

R5: Assure sufficient lead time for the market survey and tendering process for components particularly exposed to recent market pressures and volatility. Reach out to potential industrial partners in due time to ensure a sufficient number of bids for the final tendering.

R6: In order to assure a timely upgrade of the EIC related infrastructures at JLab, prepare a schedule for the required space improvements and assure a proper coordination with the JLab management for the elimination of infrastructure limitations that could limit or compromise these upgrades.

R7: Assure that the EIC hadron beam cooling related studies are sufficiently staffed and that the resources are not diluted by following several cooling options for too long.

3) CQ3: *Please assess the progress on developing the FFA-based ~22 GeV CEBAF upgrade as well as the progress in developing a positron capability for CEBAF.*

An effort has been underway for several years to evaluate the technical feasibility of an upgrade of the CEBAF energy to 22 GeV based on the implementation of a multi-turn recirculating arc employing fixed field alternating gradient (FFA) technologies. JLab is leading this effort in collaboration with BNL, ORNL, and Cornell. A preliminary concept exists with each arc supporting six simultaneous orbits, spanning a factor of two in energy, and raising the number of circulation traversals of the linacs to 10.5 from 5.5 currently. The energy gain in the CEBAF linacs remains unchanged, resulting in nearly a factor of two increase in beam energy after accounting for synchrotron radiation losses. Since the December 2021 AAC meeting the concept of accelerating positrons through the FFA arcs to 22 GeV has been dropped.

The upgrade concept builds on experience with the CBETA energy recovery linac at Cornell. Nearly all technical issues have been addressed at the pre-conceptual level and the committee believes that the current concept shows promise for a cost-effective means of upgrading the CEBAF energy to 22 GeV.

The timeframe for constructing the 22-GeV upgrade would come after the roll-off of funding for EIC construction in the mid-2030s. Proceeding will require support from NSAC and from the DOE. NSAC is currently formulating a 10-year plan. JLab looks forward to an endorsement of a focused R&D program on the 22-GeV Upgrade from NSAC and hopes for dedicated funding to start in FY25. The committee believes that at this point development of a concrete R&D plan would serve the interests of both JLab and the various stakeholders. Such a plan would identify goals, strategy, the full scope of activities, and the required resource support to complete a conceptual design around 2030.

Recommendation:

R8: Develop a detailed R&D plan for the 22-GeV FFA Upgrade.

Further comments and recommendations on the 22-GeV upgrade are included in the corresponding section of this report.

There appears to be a well-motivated scientific case for providing 12-GeV polarized positrons to the experimental program. A concept, designated Ce+BAF, has been developed. A polarization goal of >60% has been established in discussion with the user community as an optimization between e+ yield vs polarization. The concept would use an upgraded LERF facility to produce a high-power polarized electron beam that would impinge upon a metal target to produce polarized positrons. Studies are underway to optimize target materials and thickness, target configurations, and collection systems.

Conceptual development to date is appropriately focused on the key issues. Further comments and recommendations are included in the corresponding sections of this report.

4) CQ4: *Please assess the progress in R&D activities, indicating opportunities for enhancement of the lab's scientific impact in a paradigm of a multi-program national laboratory.*

As the first thing to do for the CEBAF 12 GeV reliable operation and to prepare for the future 22-GeV upgrade program, it should be essential to enhance the study and R&D for the CEBAF SRF cavity continuous degradation issues, to understand the origins, and to figure out the efficient mitigation strategy. It may critically contribute to the lab's scientific impact.

As it is noted in the report of the plasma processing effort, the degradation could be caused by particulate contamination emitted from the radiation damaged material such as organic o-rings of the gate-valves located next (or near) to the cavity structure along the beam line. This would suggest to us an important R&D direction to mitigate the continuous degradation during beam and/or RF operation. These studies may suggest to minimize possible particulate sources by replacing them with all-metal components.

The SRF technology remains a flag-ship technology for JLab at the present and in the future, in particular, for the EIC project in cooperation with BNL, ODU, and with others, as well as, in many other future accelerator programs and wider applications in industry, environment, and society.

SRF R&D for advancing thin-film and surface coating technology is particularly encouraged, as well as advanced surface treatment and plasma cleaning technology. It is important to further investigate higher temperature operation by using conduction cooling technology. It will open the door to much wider applications including the industry and environment. JLab needs to develop a longer-term strategy for the quantum computing applications.

Other related SC R&D programs reported to this review shall be important to be extended, as it is already recommended in response to the previous CQs, such as magnetrons, SSA, and AI/ML.

The next staff generation in the SRF S&T department needs to be successfully managed. The AAC would like to thank Bob Rimmer for his long-term SCRF leadership for more than 20 years.

Recommendation:
R9: Determine the origins of CEBAF SRF continuous degradation and to mitigate it for enhancing reliable CEBAF operation, and for realizing future energy upgrades toward 22 GeV. Implement continuous monitoring of the change of the degradation rate in parallel to the effort for mitigating the degradation.

5) CQ5: *Please assess our plans to expand the accelerator science and in particular engineering education, if possible indicating opportunities for further enhancements.*

The VITA program provides an excellent opportunity to broaden the education program at JLab beyond the traditional physics emphasis and into various types of engineering. The partner universities in this program have strong engineering programs, and there is significant scope of engineering R&D to support PhD work for these students. The VITA program has completed its first formative year and is currently hosting three students with four recruits pending for 2023. While the VITA program has been optimally designed to expand the education program at JLab, challenges exist with recruiting students due to the requirement that all students are either U.S. citizens or green card holders, eliminating a large base of potential students. It may be useful to host discussions with other DOE traineeship awardees to understand if they face the same challenge and what solutions they may have found. Recruiting undergraduate students from the partnering institutions with engineering programs may generate a pipeline of engineering graduate students into the program.

Recommendation:
R10: There is an excellent opportunity with the engineering emphasis to engage in graduate education in cryogenic engineering, a much-needed area in the accelerator field.

Comments on Individual Technical Talks

Topic 1: Laboratory Overview:

At JLAB the CEBAF 12 GeV program is very healthy, operating about 33 weeks in each of the past two years. Experiments are fully booked for at least the coming decade.

There is a successful partnership with BNL in management, design, and construction of the EIC collider project.

Several multi-lab partnerships are nearing the end and several are starting mainly in SCRF.

The JLAB's science mission is being diversified covering nuclear physics, EIC, Computing Technology, and Accelerator Science.

Many new staff members have been recruited and there are more needed to carry out the full laboratory's mission.

The long-term future of JLAB covers many topics including MOLLER, SoLID, CEBAF at 22 GeV, positron operation, new SRF opportunities, EIC, and advanced high-performance computer science.

Recommendation:
R11: Given the high turnover and steady ongoing recruitment of staff, carefully assess and manage the ongoing inevitable staffing commitment conflicts of the CEBAF program, CEBAF upgrades, EIC, and other technical partnership projects.

Topic 2: Overview of Accelerator Activities:

CEBAF operations and reliability remain the top priority for the accelerator program. In 2022 JLab resumed delivering 30 weeks per year of operations at a reliability of 76.3% in FY22. The CPP plan is being executed and has resulted in refurbishment of 8 cryomodules with the overall objective of 17 cryomodules over a 6 year period, as well as procurement of many critical spares. The 30 week run schedule constraints how many refurbished cavities can be installed in a SAD. CPP specifies 4 per SAD, however shortened SADs resulting from 30 weeks of operations per year only allow 2 cryomodule replacements per SAD. This will extend the time to reach 12 GeV unless gains can be made by plasma processing. Plasma processing has been successfully tested in the lab on CM100s and first in-situ processing is upcoming in the next SAD.

The SRF department continues to support CPP plan and other projects such as SNS PPU (ramping down) and LCLS-HE (ramping up). The SRF strategy was updated in 2021. The department is recovering from large staff losses a few years ago and has hired several young staff and is filling top positions with nationwide searches.

A plan for an upgrade to a 22 GeV facility utilizing the LERF is being developed. The notional timeline is tied to drawdown of EIC funds.

JLab is strongly engaged in EIC as a managing partner. The scope of responsibility is now well defined and includes accelerator design of the ERL, SRF, cryogenic facilities and magnets, and design of the 2nd IR.

Upgrades in the injectors are ongoing and will result in a higher quality beam into CEBAF.

JLab continues to have a significant engagement in accelerator science education in partnership with ODU, Hampton U, and Norfolk U, and has acquired a DOE traineeship program (the Virginia Innovative Traineeship in Accelerators program VITA) which supports undergraduate and graduate student education in accelerator physics and accelerator engineering.

Comments:
The committee was pleased to hear of a diverse portfolio of ambitious technical efforts ongoing simultaneously at the lab. This comes with the challenge of carefully managing scope and quality of deliverables in many distinctly different areas.

It is encouraging to see a well-defined EIC scope at JLab and progress being rapidly made on these areas of responsibility.

We commend the effort to develop in situ plasma processing of cavities at JLab to ease the pressure on the refurbishment program and assist in reaching 12 GeV on the planned CPP timeline. We look forward to hearing results of the first in-situ application of the plasma processing.

Several activities are being pursued relating to accelerator efficiency and sustainability. The lab should consider these as part of a broader strategy at the laboratory toward energy efficient accelerator technologies.

Recommendations: None.

Topic 3: CEBAF Operations --Introduction:

Eduard Pozdeyev is taking over as director of Accelerator Operations (starting May 16th, 2023).

Recommendation: None

Topic 4: CEBAF Operations Overview

CEBAF has been operating for 33 weeks per year in 2022 and presently in 2023. The reliability is about 76%.

Operational priorities have been defined to focus on: 12 GeV operation with 5.5 passes, delivering physics to 4 Halls, increasing the CEBAF total beam power, following the CPP, improving the cryo-module performance [e.g. trip rate and recovery time], reducing beam losses, and making shutdown and recovery faster [process-oriented approach]. All the above without compromising safety.

The operations team has 47 staff members, assigned to 4 units: Operability 3FTE, Operations 21 FTE, Accelerator Computing Group 20 FTE; Injectors 3FTE. In addition operations relies on the support from external units such as CAS, Engineering Support System, and SRF.

The staffing of open positions has been challenging, as new recruits arrive often with less experience which is not always compatible with the requirement - e.g. Crew Chiefs require on average 4.7 years of CEBAF experience. The Operations unit is working with HR to address this problem.

FY22 featured 27 weeks of physics operation with physics program in 4 Halls. Operation achieved 76.5% reliability, which falls short of the DOE requirement of 80%. Reducing the machine tuning time and reducing the fault rate and required intervention times are being analyzed for increasing the reliability.

Operations is using a Risk Matrix assessment for communicating challenges, both in staffing and with maintenance activities. Obsolescence has become a major focus of the CPP Reliability Project and the goal of keeping the trip rate below 15 per hour depends on the energy margin of the CEBAF operation.

A Scheduled Accelerator Down [SAD] Oversight Committee is implemented to control scope of activities in a given operation stop.

CEBAF operation is approved for 1.1MW, but that beam power is currently not compatible with acceptable trip rates [and thus with the required reliability].

CEBAF Performance Plan (CPP) features two distinct steering managers: a Reliability Manager and an Energy Reach Project Manager.

Machine tuning time has to be taken away from the user time. Operations is following the use of AI as an option for reducing the machine tuning time.

Comments:

Finishing the SRF upgrade and establishing more margins for the SRF operation should reduce the trip rate in the future and bring the CEBAF operation closer to the DOE requirement of 80% efficiency.

Recommendation:

R12: Follow up on the use of AI for reducing the tuning time.

Topic 5: CPP Energy Reach and SRF Production:

The CPP Energy Reach program has refurbished ~17 cryomodules over 6 years. All activities undertaken have led to the likelihood of achieving 12 GeV operation by the end of FY2023. The increased operating time has demonstrated that there is a limit of replacing two cryomodules per SAD. Assuming this constraint, the focus of near-term activities is to build the full margin of 100 MeV per linac no later than FY2028. The plan incorporates re-use of the removed C20 end groups in succeeding C75 cryomodules. The goal could be achieved by FY2025 if plasma processing produces the most optimistic outcomes and the development of this technique for C20/C75/C50 is productive.

The development of the in-situ plasma processing capability for C100 cryomodules is complete and ready to be deployed during the FY2023 SAD. Three cryomodules will be processed.

Activation of C100 and C20 cryomodules that arises from high field emission is a concern for refurbishment work as well as disposal of waste. High levels of induced activity complicate the refurbishment process.

Efforts are being undertaken to improve cavity cleanliness during the refurbishment and installation processes. This is an acknowledged important challenge to maintain the machine energy reach.

The SRF Operations organization is well staffed, and the number of term employees has been reduced. Hiring has been done as planned, addressing both replacements and DEI objectives. Some key positions remain to be filled. Detailed staffing forecasts for all known activities are available through FY2028, and reflect the ongoing evolution of support for external projects such as the SNS PPU and LCLS-II HE. Resource requirements in support of the EIC are anticipated, and will begin to dominate beginning in FY2027. The distribution of staff to projects reflects the strategic priorities of JLab.

The SRF production and testing capabilities are extensive and fully utilized, operating at capacity.

SNS PPU will be complete by the end of 2023. The LCLS-II HE production is proceeding well - the first cryomodule is being tested in the LERF. This activity is scheduled for completion at the end of FY2025. Activities to secure the necessary capabilities to enable EIC SRF production are underway. Prototype and production activities for ancillary components of the AUP crab cavities are progressing as planned.

The SRF production team is seeking to obtain ISO 9001:2015 certification. The audit process began in January 2023, and it is anticipated that certification can be obtained by the end of May 2023.

Comments:

If the anticipated gains are made during the upcoming SAD, the team will achieve 5.5 pass 12 GeV operation by the end of FY2023. This would be an excellent achievement.

Activities devoted to understanding the origins of increasing field emission and to managing field emission are very important to the ongoing reliable operation of the CEBAF machine at high energy and power.

Limited beam study time is available; so studies have to be very focused. Additional beam study time focused on improving overall RF/SRF performance could have a significant positive cost-benefit.

Legacy knowledge transfer to new staff needs to be addressed in several key areas.

The SRF Operations organization continues to provide excellent capabilities to CEBAF, the broader DOE national laboratory landscape, and the international accelerator community. The team is preparing for the advent of EIC work.

Recommendations:

R13: Demonstrate in the tunnel the capability to perform plasma processing on the C20/C50/C75 cryomodules as quickly as possible, with the sequence to be determined by the likelihood of greatest benefit.

R14: Continue to develop and deploy equipment and methods to enable cleaner cryomodule assembly and replacement activities.

R15: Fill planned staff positions for vacuum and micro-contamination engineering as soon as resources permit.

R16: Develop a decision process for the fabrication of a spare C100 cryomodule.

R17: Complete the planned process for ISO9001:2015 Certification

Topic 6: Plasma Processing Updates

Extensive plasma processing has been done at the VTA after the last review. In particular, two cryomodules were successfully processed. Although field emission onset was degraded in a few cavities, the overall performance was improved on average. It would be useful to understand the phenomenon and causes of increased field emission even though most cavity gradients improve.

On the basis of this experience, CEBAF's present optimum gas mixture is 94% helium and 6% oxygen. This mixture will be used for processing cryomodules in situ (three CMs in May 2023).

Plasma processing research will continue for C20/C50/C75 cavities. VTA tests of these cavities will include cell by cell plasma control and plasma simulation benchmarking.

Recommendation:

R18: Basic research at the VTA and off-line should include further optimization of the gas mixtures including procedures and conditions. The results should be incorporated to improve cryomodule processing in situ.

Topic 7: Updates on SSA Studies

Recent SC accelerator projects have been using or planning to use high power SSA RF sources including LCLS-II+HE, PPU, PIP-II, and EIC. Recent facilities using SSAs have been shown to be reliable and efficient. Several near term applications at JLab (e.g. LERF) to use SSAs are in the planning stages beyond those of the LERF test areas for LCLS-II and HE.

Recommendation:
R19: Future SSA applications should investigate using SSA designs with minimal changes to existing designs to take advantage of cost savings.

Topic 8: EIC Design and Accelerator Physics:

The JLab EIC project scope is now well defined and represents about 25% of the project cost and scope.   JLab leads in 18 L3 project areas. With extra funding from the Inflation Reduction Act, JLab has hired an extra 30 staff for the EIC project with the goal of doubling the EIC staff to ~70 within FY23. Jlab accelerator physics focus is on areas that are within the JLab scope. Efforts include ERL design, simulations efforts for beam-beam effects, and transverse coupled beam-beam instability analysis and the second IR design.

Currently, the JLab beam dynamics team is not directly engaged in the pre-cooling and strong hadron cooling scheme development. A workshop was hosted to discuss intersection of four beam dynamics areas (beam-beam, collective effects, dynamic aperture, and polarization). The team is looking at emerging challenges with RCS field tolerances and alternatives to the single dipole configuration.

Comments:

It was encouraging to hear that the framework for EIC beam dynamics work at JLab is now well defined and there is healthy and routine communication with the BNL counterparts.

With the JLab recent strategic hire in the area of beam cooling, an opportunity exists for the JLab EIC beam dynamics team to contribute to the development of the precooling and cooling schemes.

A large influx of new personnel, including both staff and contractors, in a short time frame can lead to both safety and technical vulnerabilities arising from gaps in knowledge and culture. Great care should be taken with onboarding and training of each new person, especially with regard to safety training. An effort should be undertaken to consolidate legacy knowledge with transfer to new staff with an emphasis on individual early-career development.

We encourage JLab staff to be on the ground as much as possible at BNL for activities within their scope which will occur in the future (equipment testing, installation, commissioning).

Recommendation:

R20: We encourage the EIC beam dynamics team to engage in the development effort for the pre-cooling and strong hadron cooling schemes.

Topic 9: EIC Engineering, Cryo, Magnets, etc.:

EIC engineering relies on about 71 staff, either partially or fully, dedicated to EIC engineering plus 10 more open positions that have not yet been filled.

The cryogenics facilities, either new or refurbished, have shared responsibilities between JLab and BNL with the designs mainly driven by JLab but BNL will be eventually responsible for the satellite plant operation and management.

The Satellite Refrigeration plants will be a “Design-to-Build” contract and the work focuses right now on defining interfaces and requirements.

The EIC team organized a Cryogenic Loads Workshop in February 2023 leading to an updated design.

The cost and schedule update for the cryogenic system has been completed.

The 2K Satellite Plants are within the long lead procurement in CD-3A. The estimated contract value is based on existing RFI data. However, only 1 out of 3 companies replied constructively to the RFI.

The EIC features over 3000 warm magnets and an initial RFI market survey has been executed. However, the design of the RCS machine has not yet been fully completed and the magnet design might still evolve over the coming months. The immediate focus of the engineering team therefore lies on RCS magnets. Design of the ESR magnets will follow. Effects of eddy currents on the vacuum chambers of the RCS and its beam should continue to be studied.

The EIC engineering team implements engineering optimizations at the end of the functional specifications. One example is the switch of water cooled to air cooled magnets.

The approach for magnet procurement is “Build to Spec”, with very detailed specifications.

The steel for the magnets is a long lead item needed to support the production schedule after CD-3. It is necessary to buy all the steel for one style magnet design contract to provide consistent magnets through production for all vendors.

Comments:

Magnet measurement facilities must be ready to support both the first prototype and production magnets to ensure quality magnets are provided to the EIC. In order to support this, the procurements for these facilities must be started prior to CD-3 approval.

Some industry areas encounter strong market pressure and have shown extreme price fluctuations. One example is the market for cryogenic plants, where the main industrial partners are engaging in new markets, e.g. liquid gas and hydrogen terminals, and where the key components are subject to strong market volatility [e.g. steel and energy prices for production processes].

Recommendation:
R21: Explore tendering procedures for EIC procurements that share the risk associated with market volatility between the industrial partner and the EIC project to avoid excessive price margins from the industrial partners. Recent experience from other projects indicates that quality of delivered products can be a significant issue as well: QA and acceptance procedures are critical.

Topic 10: EIC SRF Scope of Work:

The partnership between JLab and BNL is working well, and the definition of responsibilities and scope is well understood. Design works and R&D efforts for the EIC SRF are progressing well. The procurement efforts including long lead procurements (LLPs) are progressing as planned. Recent OPA review results - on track for CD-3A. SRF Cryomodules and HPRF Systems are significant schedule elements. The high-pressure-gas-safety (HPGS) guidelines for the EIC SRF system has been well established between JLab and BNL, referring to the US ASME (code) guideline.

Comments:

AAC encourages the JLab EIC team to perform reviews for reference designs, prototypes, and for the first article development.

It is encouraged to pursue an ISO 9001:2015 Certification, and it may allow the SRF production and operations to more efficiently handle multiple complex products from inception to delivery.

It may be an inevitable and necessary challenge to implement staff ramp up consistent with available funding considering skills mix.

Recommendations:

R22: Establish the review processes for the EIC SRF tasks to facilitate efficient transition from design to prototype development and, then, to (first-article) pre-series process.

R23: Seek early involvement of industrial partners to prepare for complex SRF production, especially for sophisticated devices such as Crab Cavities with complicated fabrication and very few production numbers.

Topic 11: EIC Crab Cavities (CCs):

For the HSR 197 MHz prototype crab cavity development, the RF design and mechanical analysis is complete. Detailed manufacturing plan in cooperation with JLab/ODU is in progress, and a cavity surface processing plan in cooperation with ANL is being implemented. The team primarily focuses on the 197 MHz cavity prototype development. The first article designs are carried out in parallel to adapt to the schedule constraint.

For the ESR 394 MHz crab cavity design status, the RF design including HOM damper designs is ongoing, and multipole analyses are ongoing to determine the specifications in designing curved pole shapes. Mechanical analysis is to be completed.

The EIC crab cavity efforts are on track for CD2.

Comments:

The AAC recognizes good progress in the EIC CC design and preparation for the prototype development, based on the long-term cooperation between JLab and ODU, including the contribution to the CERN HL-LHC CC development with the similar RFD design.

It is important to establish the process of the prototype development, the performance evaluation, and the technical transfer to industry most likely involved in the series production including the quality control, especially for the CC field quality (i.e. harmonics) to be accurately reflected in the fabrication tolerances.

The common 4-mm-thick Nb material sheets may help to simplify engineering efforts. On the other hand, it is necessary to find a solution for a stiffer (more robust) tuner mechanism against the higher rigidity of the thicker Nb sheet.

Recommendation:

R24: Seek early involvement of industry to prepare better for SCRF production stages.

Topic 12: EIC Single Cell Prototype

The ESR single cell cavity prototyping is on track at the present stage of the project. In particular, the HOM impedance requirements have been well studied, and the design takes into a sufficient account of HOM damping. No show stoppers were found at present.

The RF and mechanical design for the bare cavity is complete with fabrication design and detailed drawings are being finalized. The VTA test is planned in Q4 2023.

The cavity wall is sufficiently thick for the stress threshold, while the higher than usual tuner force is needed. The trimming and tuning test can be done at and/or before the VTA test.

The JLab EIC team understands well the challenges for the path-forward. The plans include integrated tests at LERF.

The FPC needs external Q tuning in order to cope with the wide-range of beam loading, and thus the FPC RF-thermal analysis is ongoing with external Q tuning.

Warm-cold transitions should be optimized for both FPC and beam pipes. The low impedance bellows are needed for the forward and backward beam pipes with different apertures, respectively. Finally, the design integration needs to account for all of these issues.

Recommendations: None

Topic 13: EIC Cooling:

The AAC committee heard a comprehensive overview talk of the theoretical design details of Hadron Precooling and Strong Hadron Cooling (SHC).

To reach the highest luminosity, the proton beam needs to be made flat at the collision energy with a normalized emittance ratio of εx / εy = 2.8 micrometer / 0.4 micrometer. At injection, the beam size is round with $\varepsilon x,y$ = 2.5 micrometer (normalized).

The luminosity optimization requires a vertical hadron emittance smaller than can be provided by the injector complex.

The longitudinal target emittance is achieved by splitting bunches 1:4.

The concept of pre-cooling at the injection energy with bunched beam via electron cooling is included as a vital EIC design concept in order to mitigate growth due to IBS.

The focus at the moment is to define the pre-cooling requirement. The cooling team aims at about 1-hour pre-cooling time at injection.

Initial IBS growth times without coupling are predicted at H/V/L = 4/infinity/1 hour. Coupling would imply a non-negligible vertical IBS growth time. Pre-cooling at injection therefore requires efficient compensation of the detector solenoid.

At collision the EIC relies on Coherent Electron Cooling - called Strong Hadron Cooling (SHC). It is longitudinal only at first and requires special optics with dispersion for achieving cooling in the transverse plane.

For SHC, the rms electron bunch length varies between 7 mm and 9 mm and the rms proton bunch length varies between 6 cm and 7 cm depending on the beam energy.

An alternative cooling scheme at 275 GeV only using a ring-based conventional cooling concept is being considered. Such a system is predicted to provide a cooling time of about 3 hours. The ring cooling scheme needs significantly more requirement specifications.

The cooling system design must be well understood by September 2023 for a CD3A determination by late fall. A technical review is planned for October 2023.

Comments:

There are still a lot of fundamental questions for the pre-cooler and SHC that need to be addressed.

Open questions include: Do we know and understand the electron beam noise [suggest using the IMPACT simulation tool at BNL plus experiments at FNAL]? How does operations turn the cooling system on as the e-p energy alignment should be within 1e-4, e.g. comparable to the energy spread of the bunches? The EIC team must assure that the beams are synchronous over the cooling section on the micrometer level.

It is not clear, at the moment, if the system can be tested and validated before installing at the EIC at BNL.

The mentioned alternative cooling concept at 275 GeV using an e- ring based cooling concept is not really a “Plan B”, as it has not yet been proven either to provide the required performance or overall compatible. It is not clear if it is compatible with the concept of pre-cooling at injection energy.

Analyses of the EIC integrated luminosity gains should be made from pre-cooling only and, then, from adding SHC to pre-cooling. Does SHC dominate the gain?

Recommendations:

R25: Focus activities and emphasis on the pre-cooling at injection energy. This is a “must do” for the cooling system. The online cooling during physics operation is only the second, but still important, priority.

R26: If the alternative concept based on a ring cooler is being further pursued, assure to have sufficient resources to study two different cooling concepts in parallel. If this cannot be assured, focus the activities on one cooling concept and avoid diluting the available resources at this late stage of the design on different concepts.

R27: Pursue options of testing/validating some of the electron beam and related diagnostics requirements for the Strong Hadron Cooling for EIC at the operational BNL electron cooler or the JLab LERF.

Topic 14: EIC ERL:

Achieving and maintaining high luminosity in EIC requires cooling of the hadron beam to achieve the small vertical emittance required to match the hadron and electron beam sizes, and to combat the effects of intra-beam scattering (IBS) during storage. The design, construction, and implementation of an electron cooling system to meet EIC requirements is within the JLab scope of work. Since the December 2021 AAC meeting, improved cooling modeling has led to the determination that a two-stage cooling system is required:

- A pre-cooling stage that will shrink the hadron vertical emittance following injection at 24 GeV and prior to acceleration.
- A strong-hadron cooling (SHC) stage that will combat the effects of IBS while the beam is stored at energies ranging from 100-275 GeV.

This two-stage system replaces the single-stage system described at the prior meeting. The envisioned system is beyond-state-of-the-art in several aspects, with the pre-cooling stage having a more solid technical basis than does the SHC stage at present. It seems possible there may be a viable operational scenario for EIC, at least in its initial operational stages, where pre-cooling is implemented and SHC isn't. However, the full gain potential in the integrated luminosity would not be achieved.

The present goal is to implement both cooling stages through a single energy recovery linac (ERL). The operational energy range of the ERL will span 13-150 MeV to cover both pre-cooling and SHC.

Comments:

The addition of a pre-cooling section seems well-motivated. Concepts have been developed for an ERL meeting both the pre-cooling and SHC requirements. Many of the performance demands on the ERL go well beyond current experience in existing ERLs with requirements for higher beam current, higher beam power, longer bunch lengths, lower transverse emittances, and reduced beam noise. This motivates the need for some sort of integrated systems test well in advance of project completion. Initial thinking about how to demonstrate ERL performance at an existing facility has identified a number of options including CBETA, BerlinPro, LERF, or KEK. None of these are obviously optimal. Given the importance of electron cooling to EIC performance it seems wise to establish viability of the ERL, in particular for the pre-cooling mode, early in the project.

Recommendation:

R28: Identify a strategy for demonstrating ERL pre-cooling parameters during the EIC Project R&D phase. Consider either demonstrations at an existing facility, including possible modifications to LERF, or the construction of a dedicated test facility.

Topic 15: 22-GeV CEBAF FFA Energy Upgrade:

An effort has been underway for several years to evaluate the technical feasibility of an upgrade of the CEBAF energy to 22 GeV, based on the implementation of a multi-turn recirculating arc employing fixed field alternating gradient (FFA) technologies. JLab is leading this effort in collaboration with BNL, ORNL, and Cornell. A preliminary concept exists based on an upgrade of the CEBAF injector energy to 650 MeV and replacement of the final two existing arcs (9 and A) with two FFA arcs. Each arc supports six simultaneous orbits, spanning a factor of two in energy, and raising the number of circulations traversals to 10.5 from 5.5 currently. The energy gain in the CEBAF linacs remains unchanged, although the optical functions require adjustment to accommodate the new arcs. The FFA arcs are non-scaling, meaning the beta functions (and phase advance) are different for each circulation. Synchrotron radiation becomes significant in the FFA arcs, resulting in a transverse beam emittance about a factor of three larger, and an energy spread about a factor of ten larger, than at 12 GeV. Since the December 2021 AAC meeting the concept of accelerating positrons through the FFA arcs to 22 GeV has been dropped.

The design builds on experience with the CBETA energy recovery linac operated for several years at Cornell. Both CBETA and the CEBAF energy upgrade rely on arcs constructed with permanent-magnet combined function magnets implemented as a non-scaling FFA. The designs differ however, in the need for an open midplane in the CEBAF magnet design to accommodate the much higher level of synchrotron radiation produced in the arcs.

A number of technical issues have been addressed to date including:

- Concept for a 3-pass injector to operate at 650 MeV, consistent with the requirement to maintain e+ capabilities for the 12-GeV program.
- Magnetic design of the combined function permanent magnet, including magnetic measurements on a prototype verifying magnetic performance (~1E-3).
- Optical design of the FFA arcs including matching into the linac section.
- Design of new linac optics to accommodate the FFA arcs, consistent with the existing CEBAF arcs.
- Tracking simulations through the FFA arcs, including errors.
- Design of switchyard modifications to allow the ten passes, including integration of time-of-flight chicanes required to keep the beams in phase with the RF system.

Comments:

CBETA provides the starting point for the 22-GeV upgrade concept. CBETA demonstrated multi-turn FFA operations, although only at very low beam intensities. In addition, there was some unexplained beam loss in CBETA. This needs to be understood as the 22-GeV concept is developed.

The prototype magnet has been shown to meet magnetic requirements. The next step is to understand the radiation hardness of the two candidate magnetic materials (Samarium Cobalt and Neodymium Iron Boron) in a machine environment. Samarium Cobalt was used successfully for the PEP-II IR doublets at SLAC.

The committee believes that the current feasibility design shows promise for a cost-effective means of upgrading the CEBAF energy to 22 GeV, and believes that at this point development of a concrete R&D plan would serve the interests of both JLab and the various stakeholders. Such a plan would identify goals, strategy, the full scope of activities, and the required support to complete a conceptual design around 2030.

Recommendations:

R29: Benchmark the 22-GeV FFA simulation codes against CBETA experience.

R30: Validate the loss tolerances of the permanent magnet with irradiation experiments.

Topic 16: SRF S&T and Strategy:

The SRF Strategy document was prepared in 2018 and updated in 2021, derived from the laboratory agenda.

Key resources are still missing for the successful implementation. In the document 10 to 12 staff positions were identified. At the moment, there are still 2-3 missing. The SRF team needs a succession plan, and infrastructure modernization is needed to maintain JLab as a world leading SRF R&D laboratory.

SRF capital investment on the infrastructure is slipping in schedule. The electron-beam welding upgrade has been implemented, but other items are behind the initial planning schedule. Some of the required upgrades are impacted by space constraints that need to be considered and overcome before the upgrades can be implemented.

SRF S&T scope includes the C75, QCM in CEBAF, high current operation [power limit by existing klystrons], C100 dark current simulations [collimation studies and implied heating in the cold section], particulate studies [e.g. laser particulate counter system – 100 micrometer resolution limit], plasma processing, magnetrons for CEBAF, Fast Reactive Tuner developments, and capture cavities for positrons [large aperture in CW RF operation].

EIC RF system design is well under way and is starting prototype validation.

Fundamental SRF R&D includes: Nb3Sn coating, HiQ / HiG cavity developments, understanding the origin and processes on flux trapping [temperature mapping], MgSn materials, magnetron, damped SRF cavities, multi-cell surface coating, oxide dissolution and O2 diffusion as alternative to doping, and compact accelerator applications.

Future opportunities include: thin film developments for Quantum Information systems, construction of a compact accelerator demonstrator, installation of an induction furnace which can reach very high temperatures while controlling the UHV conditions, and development of a Fast Reactive Tuner system for C100 cryomodules.

Comments:

The JLab SRF team presented an overall impressive activity portfolio with impressive progress.

Fast Reactive Tuner studies seem to be well equipped for direct application to the CEBAF program with a high probability of return on investment.

The laboratory needs to address the SCRF space limitations that are required for the infrastructure upgrade plan.

Recommendation:

R31: Develop a plan for space requirements for the foreseen infrastructure upgrades and align these space requirements with the laboratory top management and the general space management of the JLab site.

Topic 17: UITF Results (Kicker, Booster, COMTRA) and Look Forward:

The Upgraded Injector Test Facility (UITF) has been used to develop a new front-end for the CEBAF machine These new injector components will be removed from the UITF and installed in the CEBAF machine during the upcoming SAD. This facility provided capabilities for R&D related to both injector and non-injector components as well as fixed target experiments at beam energies up to 8 MeV. This was a very effective use of existing infrastructure, subject to the limitations of the shielding at the high-energy end of the machine. It enabled polarimeter and diagnostics developments, commissioning of the new booster, and a number of other technical achievements. Studies were performed on a harmonic kicker and a Compton Transmission Polarimeter. The latter, funded by a FOA, is intended to provide a capability to test a polarized electron gun at BNL where it will be delivered later this year.

Comments:

The UITF, if suitably equipped, can provide a facility for low-power accelerator science and technology and fixed-target experiments at energies up to about 8-10 MeV. Current plans call for installation of a gun to enable ongoing work at low energies in support of Wien filter optics, polarimetry, photocathode R&D, and possibly some novel applications. Future installation of a booster (e.g. Nb3Sn cryomodule) would restore prior capabilities.

Recommendations:

R32: Consider options to restore the demonstrated functionality of the UITF after several of the existing components are installed in the CEBAF facility, particularly at energies similar to that achieved with the booster cryomodule.

Topic 18: Magnetrons Update

A solid effort at JLab is underway to control commercial magnetrons in phase and amplitude to be used for various high beam power accelerators. Real progress has been made associated with recent SBIR developments.

Recommendations:

R33: Establish test capability for a prototype magnetron system capable of driving a CEBAF cavity string to fully characterize long-term stability, operational performance, and MTBF data to enable consideration as a viable option to replace the present klystron power sources.

R34: Engage an industrial partner that is qualified and prepared to carry out series production of the required magnetron systems.

Topic 19: Development of a Conduction-Cooled SRF Cavity for Industrial Accelerators

A 1-MeV, 1-MW CW SRF electron linac is under development for environmental remediation. A single cell Nb_3Sn/Nb/Cu, low-beta, SRF elliptical cavity is cooled by conduction with 4 cryocoolers.

Beam transport simulations show that for a 915-MHz SRF cavity with a geometric beta of 0.53, and an E_{acc} = 11.6 MV/m (B_p = 47 mT), a 10 % margin can be achieved.

A developed 952.6-MHz cavity in a horizontal cryostat successfully demonstrated B_p=50 mT (E_{acc} = 12.4 MV/m) with 3 cryocoolers. This is the highest record to date in a conduction-cooled cavity.

The measured micro-phonic frequency shift by the cryocoolers is low compared with a large band width arising from the heavy beam loading.

This conduction-cooled SRF technology was successfully transferred to an industry.

Comments:

Congratulations for the successful development of the conduction-cooled Nb_3Sn/Nb/Cu cavity, with the achieved field of B_p=50 mT (E_{acc} = 12.4 MV/m). There seems to have been a too small margin, in particular, for the industrial use while, also, considering the possible field degradation during the long-term operation. A future study on what limits the field is suggested.

Recommendations: None

Topic 20: Multi-Cell Conduction-Cooled SRF CM:

This work is motivated by environmental applications such as sterilization, disinfection, wastewater treatment etc. It requires a beam energy to move from 1 MeV to 10 MeV for increasing penetration depth which would significantly widening the applications in industry, environment, and medicine.

As a consequence, based on the successful progress in the single cell development as discussed above, the multi-cell (5-cells) conduction-cooled SRF CM may converge to 915 MHz and 10 MeV with a reasonable gradient.

Collaboration of JLab with ODU and JMU-MAL is ongoing.

Comments:

It may be wise to consider placing the cryocooler in an upright position for better thermal efficiency, resulting in better AC power efficiency and better maintainability.

The team may consider the use of a pure-Al strap which provides a much higher thermal conductance in cryogenic temperature for a better thermal conduction link. This technique has been well established in the application of SC quadrupole conduction cooled for the LCLS-II CM as well as in other applications. It may help to provide a compact and efficient thermal link design and efficient CM fabrication. The AAC encourages the use of this development for the environmental and wastewater treatment applications.

Recommendations:

R35: Investigate a more efficient thermal link design and better cryocooler positioning for industrial applications that require more cost-effective and compact designs.

Topic 21: SRF Collaborations (Quantum, Thin Films, PERLE)

JLab has long been a leader in SRF materials and thin film technology and for its related R&D. JLab is also engaged in a large number of synergistic collaborations to build on this expertise in SRF accelerating structures, superconducting materials and, with a particular emphasis, on new thin films. These activities include:

- SRF cavities for PERLE, and accelerator facility being developed at Orsay
- HOM dampers for the HZM Bessy facility
- Nb on Cu cavities for FCC at CERN
- Nb3Sn on Nb cavities with Fermilab
- Conduction cooled SRF cavities with General Atomics
- A quadrupole resonator (QPR) facility for testing of materials samples at JLab in collaboration with several European institutions
- Participation quantum information systems development with the Superconducting Quantum Materials & Systems Center (a collaboration centered at Fermilab)

Comments:

These programs can be naturally viewed as encompassing two types of activities: fabrication of components for off-site facilities and collaborative R&D to develop new technologies. The latter seems to be migrating strongly toward thin films, which find applications in both SRF structures and quantum information systems. While it is difficult to assess that JLab is providing leadership in the collaborative R&D efforts, it does appear that JLab's capabilities in thin film deposition are unique in several of these applications, including the quantum program. JLab is looking into the acquisition of a secondhand dilution refrigerator. This is an interesting idea that could enhance capabilities in both the superconducting materials and quantum information efforts.

Recommendation:

R36: Be diligent in continuing to align collaborative R&D activities with areas that leverage capabilities that are unique to JLab.

Topic 22: Ce+BAF Concept and High Power Target

The design study of the Ce+BAF positron concept was presented as well as the requirements for the high-power positron production target.

There is a strong scientific case for positron CEBAF operation developed from an organized large potential user base.

The present scheme would use the LERF facility to house an accelerator to produce a high power polarized electron beam which would be converted to either polarized or non-polarized positron beams. The e- injector would accelerate e- to 123 MeV at about 1 mA and then place them on a positron conversion target.

The resulting generated polarized positrons would be manipulated in a collection section to maximize the yield. Studies using simulations of optimum positron target thickness, positron phase space, and collection of non-polarized and polarized positrons have been made. Several target types are under study. Rotating and liquid metal targets are under investigation. Temperature studies are ongoing. Thermal cycling calculations are being used to study target stresses and fatigue. Tests of target properties are planned at the Mainz Microtron and at the LERF laser lab to investigate material damage thresholds. Phase I tests would be with fixed targets and Phase II tests with rotating targets. An industrial partner is studying liquid metal targets. A technical report is expected at the end of the year.

External accelerator collaborators have contributed to the positron system design.

Comments:

The addition of a positron generation system in LERF is likely a very big project. Electron and positron spin rotators are needed. The shielding needed around the positron target and collection area is likely massive. Remote positron target removal, installation and handling are likely needed.

Recommendations:
R37: Design a shielding configuration for LERF covering the target and positron capture areas.

R38: Determine if remote handling is needed for removal of used targets and capture hardware.

R39: Study the need for activated water cooling systems associated with production and capture systems.

Topic 23: Positron Collection Scheme for Ce+BAF

The study of the accelerator physics of positron generation and collection is well underway and the early results were shown. The positrons from the target have been characterized. A quarter wave transformer of 1-2 Tesla may be advantageous to help with positron capture. Both transverse and longitudinal collimation are needed. Phase space rotation is used to reduce and optimize the bunch length and energy spread. Different acceleration optimizations are needed for non-polarized and polarized positrons. Two collimation chicanes were described.

The desired goals for the positron phase space were shown along with the simulation optimized result. Many of the requirements were met but emittance and the horizontal beam size needs additional work.

Recommendations:

R40: Continue to optimize the positron parameters to reduce the normalized emittances and horizontal beam size.

R41: Since real world positron collection rates are typically lower than simulated, add as many technical effects as possible to the simulations including e- space charge, errors of component fields, and misalignments to optimize positron phase space collection.

R42: Have a detailed technical review of the positron target and capture sections to see if external experts can help with more detailed aspects of the design.

Topic 24: Fabrication of High Polarization GaAs

A new source of high current and polarized cathodes is needed because the traditional vendor has stopped making them. Polarized beams are needed for CEBAF’s long term program. High polarization cathode work at JLAB has three technical approaches: MOCVD, CBE/MBE/ and nanostructured. Multilayered strained superlattice cathodes with a distributed Bragg reflector show good promise. MBE grown InGaAs/InAIGaAs superlattice cathodes are also good candidates. Unconventional nanostructured (pillars) semiconductor photocathodes are being explored on the basis of recent progress. The JLab’s microMott polarimeter is being repaired to be used for cathode evaluation of QE and polarization, and plans are proposed for upgrades.

Recommendation:

R43: Make a plan to converge on the best route to a sustainable cathode design and manufacturer to provide for the ongoing CEBAF program.

Topic 25: Reaching Lower Pressure in Photo-Guns

A low vacuum pressure is crucial for the performance of photo-guns, in particular, those with high polarization and long lifetime. Steady progress in reaching lower vacuum pressure in photo-guns has continued over 20 years. The pressures have improved from 10-10 Torr to around 10-12 Torr. Lower pressure might be achieved by the recent innovation, making use of low-carbon steels for vacuum chambers.

The recent ECA proposal would be a 5-year development of an electron source with improved vacuum (e.g. one or two orders of magnitude lower) in support of providing e- beams with 90% polarization and with charge lifetime > 1kC at 10 mA average current on the basis of the low-carbon steels use.

Comments:

Committee endorses the ECA proposal, which will lead to good nuclear physics experiments.

Recommendations: None

Topic 26: JLAB/CEBAF AI/ML Overview:

The AI/ML program at JLab has advanced greatly in the past few years. Real beam and RF data from CEBAF is being used to try to predict upcoming CEBAF faults.

Comments:

It would be useful to apply the AI/ML approach to get some hints to investigate the reasons for the continuous RF gradient degradation, possibly linked to the beam operation.

We continue to encourage the team to develop and apply AI/ML, considering whether additional diagnostics may be needed, in order to enable simultaneous optimization of the beam delivered to all of the end-stations.

Recommendation:

R44: Continue to enhance the analysis of beam and RF data to enable more accurate prediction of future fault events.

Topic 27: ML CEBAF Efforts:

Two specific efforts are underway to apply machine learning (ML) to the operating CEBAF machine.

There is an established and growing effort to identify field emission from C100 cavities and to then use ML to optimize the gradient distribution to minimize the field emission. If this is successful it could contribute to a reduction in the frequency of fast shutdown events or a reduction of time spent in beam transport recovery. At present, operators manually redistribute gradient performance to manage radiation levels, a process that is time intensive. New models have been developed based on data obtained from gradient scans that require beam studies, as well as parasitic RF trip data. A real-world test of the new approach conducted in late FY2022 demonstrated broad agreement between the model and reality for 6 cryomodules.

The second focus area is application of ML to identify unstable C25 and C50 cavities that contribute to beam instability and loss, and hence lower reliability. Two models are being developed, one based on archived EPICS data and one based on data from new fast DAQ chassis for the C25/C50 cavity RF control modules. The autoencoder model that mines slow EPICS data is deployed to present results to the operators and technicians. It provides data for both linacs and enables operator interrogation of particular cavities. It allows problematic cavities to be identified, but has not provided information yet to understand system limitations to high power operation. The fast DAQ system captures and analyzes RFCM faults. These data have been processed using two approaches, and the principal component analysis approach looks quite promising. Further work is underway to refine this new system, but deployment of a new DAQ chassis is slow because of residual conditions arising from the pandemic.

The most significant impediment is the ability to recruit post-docs and students to work on these activities, which is addressed elsewhere in this report.

Comments:

It would be interesting to compare the speed with which the ML tool can achieve results with that typically achieved by operations staff using skill of craft. The forward looking program will likely lead to further improvements. It is also gratifying to see the doubling of the number of neutron detectors which will further support this initiative.

Recommendation:

R45: Continue to develop both of these new AI/ML tools to aid in identifying and responding rapidly to real-time linac performance issues.

Topic 28: Educational Updates & VITA:

JLab continues to have a strong graduate education program in partnership with ODU primarily and other universities, with current graduation rates of 4 PhDs/year.

A partnership for education in accelerator science and engineering between JLab, ODU, Norfolk State University, and Hampton University called the Virginia Innovative Traineeship in Accelerators (VITA) was awarded a DOE traineeship grant.

The VITA traineeship has a significant thrust in accelerator engineering with two graduate students in this part of the program currently.

The structure of the VITA is now functional with students from each of the partnering institutions attending new courses at ODU, and an active recruitment program for both graduate and undergraduate students ongoing.

It is challenging to meet the quota requirements for the Traineeship program due to the requirement that the students be US citizens or green card holders, which eliminates a large both of otherwise eligible and attractive student candidates.

Comments:

The traineeship presents a unique opportunity to expand and broaden graduate education in accelerator science and engineering.

Consider using the traineeship to educate students in the field of cryogenic engineering, which is a noted area of need for engineers at accelerator facilities.

The traineeship should capitalize on JLab's large scope of EIC responsibilities and the recent Jlab strategic hires to initiate thesis projects related to the EIC subject matter.

Recommendations: None

Topic 29: SBIR Overview:

JLab has a very robust SBIR program. About 4 to 5 Phase I and 4 to 5 Phase II SBIRs associated with the laboratory are funded each year. The acceptance rate is about 30 to 40% which is impressive. These SBIRs cover a wide range of topics and several funding agencies. Industries are eager to work with JLab because of its diverse science program. Several of the ongoing SBIRs were described.

Recommendations: None

Appendix A: JLAAC-2023 Review Agenda

Accelerator Advisory Committee Agenda
March 8-10, 2023
Hybrid meeting (all time below in Eastern Time)

Wednesday, March 8

08:30 – 09:00	*Executive Session*	
09:00 – 09:30	Director Welcome/Lab Overview	Henderson
09:30 – 10:10	Overview of Accelerator Activities	Seryi

CEBAF Operations

10:10 – 10:15	CEBAF Operations – Introduction	Pozdeyev
10:15 – 10:30	*Break*	
10:30 – 11:15	CEBAF Operations Overview	Michaud
11:15 – 12:00	CPP Energy Reach & SRF Production	Reilly
12:00 – 13:00	*Lunch Break*	
13:00 – 13:30	Plasma processing updates	Powers
13:30 – 14:00	Update on SSA studies	Hovater

EIC

14:00 – 14:30	EIC Design and Accelerator Physics	Satogata
14:30 – 15:00	EIC Engineering, Cryo, magnets, etc.	Michalski
15:00 – 15:15	*Break*	
15:15 – 15:40	EIC SRF scope of work	Daly
15:40 – 16:00	EIC Crab Cavities	De Silva
16:00 – 16:20	ESR Single Cell Prototype	Guo
16:20 – 16:40	EIC ERL	Benson
16:40 – 17:00	EIC Cooling	Nagaitsev
17:00 – 18:00	*Executive Session*	

Thursday, March 9

08:00 – 09:00	*Executive Session (can be used for Homework Q&A)*	

Accelerator R&D

09:00 – 09:30	FFA 22 GeV CEBAF Energy Upgrade	Bogacz
09:30 – 10:00	SRF S&T & Strategy	Rimmer
10:00 – 10:20	UITF results (Harmonics kicker, Booster comissioning, COMTRA) and look forward	Bruker
10:20 – 10:40	*Break*	
10:40 – 11:00	Magnetrons update	Jordan
11:00 – 11:20	Conduction cooled single-cell SRF CM	Ciovati
11:20 – 11:40	Multi-cell conduction-cooled SRF CM	Vennekate
11:40 – 12:00	SRF Collaborations (Quantum, thin films, PERLE)	Valente
12:00 – 13:00	*Lunch Break*	
13:00 – 13:20	High power target for e+ LERF concept	Ushakov
13:20 – 13:40	Positron collection scheme for Ce+BAF	Habet
13:40 – 14:00	Fabrication of high polarization GaAs	Stutzman
14:00 – 14:20	Reaching lower pressure in photoguns	Mamun
14:20 – 14:40	JLAB/CEBAF AI/ML overview	Tennant
14:40 – 15:00	ML CEBAF efforts	Turner
15:00 – 15:20	*Break*	

Educational and Industrial Outreach

15:20 – 15:40	Education updates & VITA	Krafft
15:40 – 16:00	SBIR overview	Spata
16:00 – 18:00	*Executive Session and Report Writing*	

Friday, March 10

08:00 – 10:00	*Executive Session*
10:00 – 10:30	*Q&A with JLab Staff*
10:30 – 11:30	*Executive Session*
11:30 – 12:30	Closeout