Report of the CBETA Advisory Committee, May 9/10 2019, Ithaca, New York

Committee Members

Sergey Belomestnykh (Fermilab), Steve Benson (JLAB), Oliver Brüning (CERN), Wolfram Fischer (BNL), Mike Harrison (BNL, Chair), Shinji Machida (Rutherford), David Rubin (Cornell).

Introduction

The review took place over two days. The first day was given to presentations by the Project together with a brief tunnel tour. The second day consisted of executive sessions followed by a close-out. The agenda is given in Appendix 1. The charge to the Committee is given in Appendix 2.

The Committee welcomed Steve Benson as a new member.

Overall the Committee was pleased with the progress since the last meeting, recent results of the beam tests and believes the Project is on track to accomplish the near-term Project performance milestones of single turn beam transmission with energy recovery. The report addresses the charge questions and then provides the committee comments on the presentations.

Charge #1: **<u>Prior recommendations</u>:** Did the project respond appropriately to the recommendations of the last Advisory Committee meeting in October 2018?

Response: *Yes. The Committee agrees with the Project that they have addressed the suggestions (not recommendations) from the last review. In particular the Equipment Protection System has made commendable progress. The Committee was less convinced with the response to the commissioning planning item but received a more detailed report in the Q&A session.*

Charge #2: **<u>Optics validation:</u>** Does the final analysis of the Fractional Arc Test results quantitatively validate the predicted optics?

Response: *Almost. The Committee believes there is good qualitative agreement between the nominal optics and the results of the fractional arc test. The relatively short lever arm of the test limits any extrapolation to the complete ring optics with the desired confidence. The Committee believes that the full ring results will allow definite statements to be made in this regard soon and given the excellent field quality of the shimmed permanent magnets expects a confirmation of the nominal optics.*

Charge #3: **Single pass commissioning:** Is the project likely to meet the goals of Milestones 9 and 10 by June 30 and October 31, respectively?

Response: *Yes. The recent demonstration of a relatively complete beam circulation without the benefit of the dipole correction system goes a long way to completing milestone 9. Other single pass goals of energy acceptance and an energy scan should be relatively straightforward given the recent progress. The necessary hardware to complete these tasks will be available in the very near future.*

The Project has set a stretch goal of completing the energy recovery milestone 10 by July 15 (before the month-long maintenance shutdown and ~3 months before the nominal date). The Committee believes this is certainly feasible. There is a slight caveat in regard to beam halo and energy recovery efficiency, but we feel at these intensities it is unlikely to be an issue.

The Committee notes that the NYSERDA KPP's can be potentially demonstrated in this mode. With a beam current of 1 mA energy recovery efficiency i.e. beam losses may start to present a challenge.

Charge #4: **Multi-pass commissioning:** Is the strategy for moving from one-pass to multi-pass commissioning well thought out? Does the plan have sufficient flexibility to be able to respond to risks, should they occur? What are the leading risks?

Response: *The Committee was shown a multi-pass roadmap of technical steps as well as a strategy to achieve it. The roadmap was thoughtful and comprehensive. The Project has decided to prioritize 4-turn operation. The Committee broadly concurs with this approach.*

Flexibility is limited in some regards due to hardware modifications involving breaking vacuum, needed to switch between operating modes. This introduces an unavoidable downtime penalty of several weeks. More flexibility would be helpful but infrequent changeovers can suffice if well planned.

There are still non-trivial risks remaining; these involve short-term equipment availability, manpower resources, multi-pass beam dynamics, KPP requirements, and the milestone schedule.

Charge #5: **Goal prioritization:** Are the relative priorities of achieving the multiple technical goals (total current, single bunch charge, recovery efficiency, et cetera) correct?

Response: *Sort of. The Committee feels that the response to this charge question depends on how one views 'correct'. The relative priorities will change depending on whether one emphasizes physics progress or the KPP's. The Committee tends towards the view that the KPP's should take preference at some point in this regard but notes that April 2020 is the required date for the KPP's rather than the end of the calendar year for other milestones. In view of this the Committee supports the plan to implement 4-turn operation as soon as feasible and de-emphasize 2-turn. We also note that there is likely to be a short window in July where the equipment protection system readiness would allow a push towards higher intensities. It will be important to take full advantage of this period before the change over to 4-turn operation in the upcoming shutdown since this will likely limit higher intensity operation in the near term. Since it is improbable that 1 mA intensities will be achieved during this period then it is important to establish a set of criteria to determine when a change back to 1-turn operation is made to demonstrate the KPP goal.*

Charge #6: **Strategies for future support:** Have the PIs identified promising strategies for obtaining financial support for continued operation and exploitation of the CBETA facility after the end of NY State funding for construction and commissioning?

Response: *Not yet. This is a critical issue. NYSERDA funding will expire soon (~early 2020) and it would not be rational to construct CBETA without exploiting it fully.*

The Project has estimated that a sum of ~$2M/yr is needed to sustain an ongoing program. This seems reasonable to the Committee. This is not a huge amount, but it is also non-trivial. The Project has identified DOE NP as the most likely source of any subsequent operations funding. The Committee agrees with this assessment. To maximize the chance of success in this regard the Committee feels that much closer alignment with the existing EIC programs at BNL and JLAB will be required. Any approach to EIC hadron cooling must be based on the parameters as described in the EIC PCDR's. The ability to outline a focused multi-year program of R&D will be a crucial element in this regard. We did not see this to any degree. In addition, we believe that discussion at several levels will be required for success: agency level, lab level, technical level. This process needs to start very soon given the imminent funding shortfall.

Other possible funding sources were outlined. These are unlikely to be as significant as EIC related ones but should still be pursued.

BEAM DYNAMICS

Commissioning Physics Goals: 150 MeV 4-pass energy recovery will be difficult and requires an accurate optics and lattice model. Furthermore, an accurate determination of the optimum cavity phase settings and control and an accurate calibration of the beam current and beam loss monitors are mandatory before undergoing the transition to 4-turn beam circulation. The Advisory Committee supports this approach and the efforts of getting as many and as accurate beam measurements done before changing the machine configuration to 4-turn operation. However, the project needs to pay sufficient attention to achieve the KPP of 1 mA with 1-turn ERL operation. Characterization and optimization of the machine is important, but the purpose of the energy scan for example should be more focused on aspects such as BPM calibration because FAT has already given sufficient machine information.

Commissioning Results and Status: First commissioning measurements were performed at a beam energy of 42 MeV and focused on the dispersion and R56 measurement. Energy scans of the MLC showed that a best fit of the measured optics functions can be obtained by scaling the energy settings of the MLC by an empiric factor of 1.018. This apparent energy-mismatch seems to get confirmed by FFA Arc measurements where a fit of the difference orbits after threading indicates a beam energy of 41 MeV (we understand that it is a preliminary value) instead of the set value of 42 MeV. The Advisory Committee encourages the CBETA team to pin down the origin of this apparent energy error as this might point to fundamental setting errors that could be amplified with multiple passages through the MLC and make the commissioning of the 4-pass energy recovery even more challenging. It would be good to specify what level of energy accuracy is required for making the multi-turn commissioning less challenging.

The first beam measurements seem to indicate a rather significant beam halo of approximately 3%. The origins of this large beam halo need to be well understood [e.g. cathode or beam scraping at aperture bottlenecks] and compensatory measures need to be identified before. Without understanding the origin of the beam halo the operation risks too high beam losses in the Halbach magnets when pushing the beam intensities or undertaking the transition to 4-pass operation.

Coherent Synchrotron Radiation Simulations: The most recent CBETA CSR simulations show significant beam perturbations [up to 2% for 1 pC beam currents in 4-pass configuration] and some particle losses [9 out of 100k]. A beam charge of 25 pC is required for achieving the KPP goal of 1 mA. The simulations therefore seem to indicate that it will be difficult, if not impossible, to achieve this KPP in 4-pass configuration. Simulations for 1-pass operation show that a bunch charge of 25 pC should still be acceptable for 1-pass operation.

The Advisory Committee was surprised about these strong limitations imposed by CSR and wonders why this limitation was not more clearly discussed and underlined in the earlier phases of the CBETA project and in particular when fixing operational goals for the CEBETA operation [e.g. 40 mA in 4-pass operation].

In view of these results the Committee did some post-meeting homework by discussing CSR with beam dynamics specialists at JLAB. Their analysis (for similar scenarios) indicates that these effects should be small for bunch charges well in excess (128 pC) of those proposed for CBETA. The JLAB team stressed that these calculations can be difficult to perform and that the details of the choice of the simulation parameters are critical to achieving a credible result. This discrepancy needs to be resolved with some urgency

The Advisory Committee thus suggests more CSR simulations and benchmarking with other machines in order to validate (or disprove) these results.

In addition, the Committee encourages the CBETA team to verify potential other intensity limitations for the multi-turn operation, such as BBU, another intensity depending effects for multiple-turn.

HARDWARE

Installation: The CESR / CHESS upgrade last summer started late, which also delayed the CBETA installation by 1 month. The installation task went relatively smoothly, and this resulted in Milestone 8 (completion of ring installation) achieved only 2 weeks behind schedule. The schedule for the upcoming (and final) installation period (15 July to 15 August) is under development and should be complete within a week. Three magnetic elements from the splitter region are not yet available (septa 1, septa 2, long water-cooled quad). These are needed for passes 2-4, the mechanical design for 2 of the 3 magnets is complete.

The CBETA management team explores technical support from BNL to accelerate hardware construction and installation – these requests still need to be evaluated by C-AD management. Single turn operation will proceed until the 4-turn hardware is complete.

Equipment protection system: The Committee was impressed in the progress of this system. The primary design criteria for the EPS is to prevent equipment damage from the high-power electron beam (up to 6 MW) and limit the radiation to the permanent magnets to a level acceptable for the lifetime of CBETA. It is necessary to be operational before any attempt is made to raise the beam intensity from the present nominal value.

The EPS design goals, damage thresholds, diagnostics, machine modes, implementation and operation were defined, documented (in a live document) and Stage 1 was reviewed on 1 March 2019 by a Cornell/BNL review team (Stage 1 limits the average beam power in the FFA loop 200 pA to prevent permanent magnet damage). This EPS design document should be version controlled – the present live document makes it difficult to reconstruct the version used at certain points in time

The configuration control of the EPS should be limited to a few experts, with documented changes, EPS certification should also be documented (e.g. in elog). Like CBETA the EPS is in commissioning; for safe beam operation it is necessary that the CBETA beam commissioning does not get ahead of the EPS commissioning. The Project reported that the EPS should be fully certified by the beginning of June.

RF systems: Various hardware/firmware problems with Solid State Amplifiers, RF power circulators, etc. are being addressed. Some of the problems were solved, other alleviated to the extent that the RF systems appear to be ready for operation. Mild Committee concerns involve the following: The MLC tuner motor assemblies (harmonic drives) are considered to be vulnerable to mechanical damage – the Project should try to minimize cycling. Noise/crosstalk on LLRF cavity field signals could affect achievable field stability during operations. Discrepancy of the MLC vertical offset measured during alignment vs the beam-based measurements is a concern. The re-appearing of the 41 Hz microphonics line while not affecting the operation, should be investigated and understood.

The remaining issues to be resolved before beam operation are: 1) determining whether to use JT valves or 2-K/2-phase heaters to regulate LHe level with RF ON and demonstrating stable operation; 2) fixing LLRF issues on MLC cavity #5; 3) verifying that the 59 MeV energy gain is still achievable; and 4) resolving the beam energy calibration discrepancy (~2% - most likely not the RF system issue).

Instrumentation: Laser synchronization has a couple of issues: unresolved long-term drift and phase jumps after the laser loses lock and has to be re-synchronized (this is an implementation issue). These are not show-stoppers.

Remaining things to complete before beam operations include: 1) The Beam arrival monitors hardware still has to be tested; 2) EPS requires running cameras at 1 Hz rep rate – this is an unresolved issue; and 3) Complete the Fast Loss Monitor data acquisition.

The beam position monitors and associated electronics are working well with only a single dead channel in the initial testing. Some additional timing work remains to be performed. The Committee anticipates significant effort will be needed to learn how to measure the orbits of different energy beams. BPM features demonstrated to date include single pass measurements, asynchronous operation and time delay scans. This bodes well for future commissioning progress.

Controls: The Committee was impressed by the report of the online modeling capabilities implemented in the control system. Based on the BMAD simulation package, features include modeling propagation of single particles/beam through injector, splitters, FA, including BPM noise, misalignment, etc. and a platform to develop measurement techniques. Real conditions (machine state) are readily incorporated into the model. Streamlined analysis of measurements, understanding of dependencies when measuring and correcting the orbits, dispersion, with non-vanishing emittance and BPM offsets, etc. are all facilitated by these techniques. Thus, the control system provides a teaching tool permitting offline investigation of machine properties. These features allow for straightforward comparisons of the model and beam measurements.

FUTURE

Commissioning The Project laid out the roadmap for commissioning and achieving the technical milestones:

Single Pass Beam Energy Scan

- Demonstrate orbit correction through arc to R1 splitter (depends on availability of corrector power supplies)
- Raise MLC energy in ~2 MeV steps and measure orbit, tune, dispersion, beam profiles, BPM offsets

Single Pass Beam Energy Recovery

- Timing – tune splitter bellows for appropriate delay
- Cavity phase/voltage for energy balance
- Increase current and identify limits

Four passes with energy recovery

- Beam energy / cavity phase
- Test multi-energy BPM response
- Multi-energy orbit correction

The Committee agrees that this represents the appropriate steps but has little to add.

Scientific potential and future options: The CBETA team has done a good job of laying out the path forward with decision points and milestones to accomplish the NYSERDA goals and KPPs before the end of the project. The current plan is to complete all the single pass running by July 15 and then to install the 4-pass hardware and work on multi-pass operation. Two-pass operation would be skipped unless some hardware failure forces them to go there.

This plan was augmented in the Q&A session with backup plans if the KPP goals are not reached by July 15. Hardware necessary to minimize halo and CSR would be installed and the single pass configuration would be re-installed. This looks like a reasonable approach to the Committee.

The problems with CSR may limit future options, especially operation at high current with high charge. This issue must be explored in more depth before making any final conclusions. The possibility of high current at low charge is still a valid goal however and the RF and halo control are still useful future research topics. Operation with multiple passes at low charge is also possible and can be used to test several fundamental ERL physics issues. The multi-pass ERL can also be used for several applications such as a dark matter search facility or for Compton backscattering studies.

EIC studies should be mainly single pass but should push the charge up as high as possible. The overlap with EIC might be limited due to CSR effects but characterization of CSR vs. charge and halo and RF studies could still be carried out and could provide valuable input to the EIC design studies.

The impact of CBETA on EIC: All EIC designs use hadron cooling to enhance luminosity. The required currents and energy mean that the optimum solution to date is an ERL. The requirements for a CeC and incoherent cooler were presented in this talk. Both require very high power circulating beams that far exceed the current state of the art. CBETA could contribute to the design validation of such an application.

Proposals should concentrate on existing EIC baseline designs and should explore how CBETA can validate these baseline designs. The project laid out a good approach for this type of proposal.

APPENDIX 1

CBETA Advisory Committee Meeting
374 Wilson Lab, Cornell University
May 9-10, 2019
v5.3

Time	Title	Presenter
7:45	**Van Pickup at Hotel Ithaca**	
8:00	Breakfast snacks for review panel	
8:30	Executive session	
	INTRODUCTION	
9:00	Welcome	Julia Thom-Levy
9:10	Project status & overview	Steve Peggs
9:40	Scientific potential and future options	Georg Hoffstaetter
10:10	Commissioning Plan	Adam Bartnik
10:40	Coffee break & Tour of CBETA	
	HARDWARE	
11:10	Equipment Protection System	Nilanjan Banerjee
11:30	RF System: status and performance	Peter Quigley
11:50	Beam Position Monitor performance	Rob Michnoff
12:10	Instrumentation: portfolio & future	John Dobbins
12:30	Executive session and lunch for committee	
1:10	Control system and CBETA-V	Kirsten Deitrick
	BEAM DYNAMICS	
1:30	Commissioning physics: goals and opportunities	Scott Berg
2:00	Commissioning results and status (including FAT)	Colwyn Gulliford
2:30	Coherent synchrotron radiation simulations	Wei Yuan (William) Lou
3:00	Coffee break	
	THE FUTURE	
3:10	4-pass field-map simulations	Francois Meot
3:40	Installation status and schedule	Karl Smolenski
4:10	Impact of CBETA on EIC: hadron cooling	Dejan Trbojevic
4:40	Executive session	
5:30	Discussion with CBETA / homework	
6:00	Adjourn	
7:00	Dinner with committee and speakers	Agava (381 Pine Tree Rd, Ithaca)

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7:45	**Van Pickup at Hotel Ithaca**	
8:00	Breakfast snacks for review panel	
8:30	Executive session	
9:00	Homework responses / open discussion	
10:00	Executive session	
12:00	Lunch for committee	
1:00	Close out with CBETA staff	Mike Harrison
2:00	Adjourn	

APPENDIX 2

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managed by Brookhaven Science Associates
for the U.S. Department of Energy

CBETA Advisory Committee meeting
May 9 & 10, 2019
Charge to the Committee

The next meeting of the CBETA Advisory Committee will take place on May 9 & 10, 2019, at which time there will have been significant beam commissioning experience with Task 9, "Single Pass Beam Energy Scan". The following task, "Single pass beam with energy recovery", is scheduled to begin on July 1, 2019.

The Committee is asked to evaluate the current technical status of the project, and the path towards achieving its full scope before the end of the project on April 30, 2020. The committee is also asked to identify any technical elements on which the team should focus in order to better execute the project.

In particular the review committee is requested to evaluate:

1. **Prior recommendations:** Did the project respond appropriately to the recommendations of the last Advisory Committee meeting in October 2018?

2. **Optics validation:** Does the final analysis of the Fractional Arc Test results quantitatively validate the predicted optics?

3. **Single pass commissioning:** Is the project likely to meet the goals of Milestones 9 and 10 by June 30 and October 31, respectively?

4. **Multi-pass commissioning:** Is the strategy for moving from one-pass to multi-pass commissioning well thought out? Does the plan have sufficient flexibility to be able to respond to risks, should they occur? What are the leading risks?

5. **Goal prioritization:** Are the relative prioritizations of achieving the multiple technical goals (total current, single bunch charge, recovery efficiency, et cetera) correct?

6. **Strategies for future support:** Have the PIs identified promising strategies for obtaining financial support for continued operation and exploitation of the CBETA facility after the end of NY State funding for construction and commissioning?

The meeting will take place on May 9 & 10 in Ithaca. Please present closeout conclusions to the CBETA project team prior to adjourning and make a written report available to the Oversight Board by May 31.

I very much appreciate your willingness to lend your time and expertise to this important step in the CBETA review process and look forward to receiving your assessment.

Sincerely,

Berndt Mueller
Associate Laboratory Director for Nuclear and Particle Physics
Chair of the CBETA Oversight Board
Brookhaven National Laboratory

Table 1: Key Performance Parameters and ultimate design parameters.

Parameter	Unit	KPP	Design
Electron beam energy	MeV		150
Electron bunch charge	pC		123
Electron source current	mA	1	40
Bunch repetition rate (source)	MHz		325
RF frequency	MHz	1300	1300
Injector energy	MeV		6
RF operation mode			CW
Number of ERL passes		1	4
Energy apertiure of arc		2	4

Table 2: High level technical milestones.

#	Technical milestone	Contract	Actual
	NYSERDA funding start date		31-Oct-16
1	Engineering design documentation complete	31-Jan-17	31-Jan-17
2	Prototype girder assembled	30-Apr-17	30-Apr-17
3	Magnet production approved	30-Jun-17	23-Jun-17
4	**Beam through Main Linac Cryomodule**	**31-Aug-17**	**16-Jun-17**
5	First production hybrid magnet tested	31-Dec-17	21-Dec-17
6	**Fractional Arc Test: beam through MLC & girder**	**30-Apr-18**	**20-Apr-18**
7	Girder production run complete	30-Nov-18	21-Nov-18
8	Final assembly & pre-beam commissioning complete	28-Feb-19	13-Mar-19
9	Single pass beam energy scan	30-Jun-19	
10	Single pass beam with energy recovery	31-Oct-19	
11	Four pass beam with energy recovery (low current)	31-Dec-19	
12	Project complete	30-Apr-20	