Report of the CBETA Advisory Committee

October 8th, 2018, Ithaca, New York

Committee Members

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

Format

In a change from the usual two-day reviews this meeting was held electronically with a highly abbreviated four-hour agenda of short talks covering the present status of the CBETA Project and results from the Fractional Arc Test conducted earlier this year. The agenda is given in Appendix 1. The close-out was conducted verbally by the individual Committee members after a short executive session. The charge to the Committee is given in Appendix II.

Overall the Committee was encouraged by the information presented and believes it should be possible to meet the Key Performance Parameters (KPPs) in a time period consistent with the commissioning plan.

1) Charge #1: ***Fractional Arc Test:*** *technical successes, hardware performance, results achieved, and lessons learned.*

Response: *The Fractional Arc Test (FAT) was a highly visible major Project milestone and goal for the CBETA commissioning. Overall the Committee views it as a notable success and recognizes that it was reached 10 days before the nominal milestone date. The Committee encourages continued analysis of the data obtained during the test.*

The preparation for the FAT featured the development of extensive modelling tools [e.g. GPT for the injection and MLC part, BMAD for the arc and settings optimization using MOGA] that have been combined to provide a front-end simulation tool that has been connected with the CBETA control system to provide a virtual machine online model [CBETA-V] for system tests and commissioning. This is certainly a good approach and provides a valuable asset for the full commissioning of CBETA

The FAT was organized in two parts: a fast track approach for achieving the FAT milestones [beam through the splitter, MLC cavity calibration] followed by secondary measurements aiming at a more detailed and in-depth analysis [e.g. orbit response matrix measurements, dispersion and R56 measurements, oscillations versus Beam Position Monitor (BPM) offsets and tune, path length adjustment measurements]. These detailed secondary measurements certainly provide a solid basis for the full commissioning of the CBETA machine.

Overall, the FAT test provided a good qualitative agreement between the simulation and measured data. However, there were still quantitative differences between the measured and modeled data [e.g. coupling and tilting of the distributions and the tail formations of the distributions]. Some of these differences can be explained by readjusting empirically the quadrupole calibration [e.g. by 4%]. For the final CBETA commissioning one will worry about the formation of beam halo and thus about potentially small differences between the model and the real machine. The Advisory Committee would therefore suggest a more detailed analysis with the goal of achieving not only qualitative, but also quantitative agreement between the model and measured data and encourages the CBETA team to develop the required tools for such a detailed analysis in time for the full machine commissioning in 2019.

2) Charge #2 ***Technical readiness:*** *(Halbach girders, splitters, RF, et cetera). Delivery status, issues, and installation readiness in the intensive construction period leading up to technical milestones 7 and 8 ("Girder production run complete" and "Final assembly and pre-beam commissioning complete").*

Response: *The Project is a few weeks away from starting the final installation phase with a goal of achieving milestone 8 by the end of February 2019. This will be a challenge but the preparations to date are consistent with this result. The Committee anticipates that the beam splitting regions will be the deciding factor in this regard. The major accelerator systems benefitted greatly from the FAT and the Committee expects all systems to be available as and when required. A review of the machine protection system is suggested.*

Accelerator Design: Overall a good and very mature design. Most items have been frozen and stable since August 2017 with the optics design developed with BMAD using detailed field maps. Each energy pass has R56 = 0 as a design goal for a full turn. The optics development led to an increase of gradients for some of the magnets which was implemented in December 2017 [length increase of a quadrupole]. Reference design configurations have been made for 1-pass and 4-pass operation with energy recovery. Energy recovery configurations with 2 and 3 passes (and lower beam energies) are kept only as a backup. But the optics for these configurations are readily available.

The only missing item in the lattice and optics design is the dump line. The committee felt that the dump line is a very critical item as it has to provide sufficient energy acceptance to accept the beam after deceleration and potential deformation due to errors along the trajectory through CBETA. The advisory committee suggests finalizing the dump line lattice and optics as soon as possible and preparing tools and procedures for measuring the energy acceptance and aperture of the line in the final configuration in CBETA.

Permanent Magnet Girders: There has been good progress in this area since the last review. The Fractional Arc Test demonstrated qualitative agreement between measured beam optics through two Halbach cells and the design. Production of the Halbach elements, the correctors and girder integration at BNL are all consistent with the nominal installation schedule and associated Project milestone. The magnetic field is measured and shimmed for each magnet and has resulted field quality well within tolerance. A number of girders have been transported from BNL to Cornell uneventfully. Start of installation waits for completion of Cornell infrastructure. Barring unforeseen circumstances, the Committee expects the Project to meet the girder complete milestone on time.

Beam Splitters and Combiners These areas of the machine separate (and recombine) the 4-pass beam to allow for individual path length and optics adjustment and multi-energy passage through the cryomodule. The Fractional Arc Test included testing the low energy splitter beam line, S1. Extensive measurements characterized trajectory and beam optics in S1 demonstrated qualitative agreement with design. More detailed and quantitative analysis is in progress to provide quad calibration, alignment, and BPM offsets. Online software that includes systematic measurement of beam parameters with analysis (CBETA-V) was tested successfully and proven to be an effective diagnostic tool. Measurements indicated the importance of vertical focusing in the dipole fringe fields. The CBETA-V model will be extended to include the fringe focusing.

The mechanical design is challenging due to the minimal transverse space available. Much progress is evident since the last review with the layout finalized and magnet design completed. Vendor delivery of the magnets is underway, but a significant number remain to be delivered. The Project must continue to work closely with magnet suppliers as magnet delivery is the critical path. A small number of elements still need their design to be completed. The committee was pleased with the close and effective collaboration between BNL physicists designing beam optics with Cornell magnet and mechanical engineers vetting magnet parameters and fitting all the components together into the very tight space. Assembly will be a challenge, and will require continued careful planning, attention to detail, and cooperation. The measurement plan for the splitter magnets was not clear.

Although much has been done, much remains and there is no apparent schedule float with respect to the installation complete milestone. The Committee suspects that these accelerator sections will be the defining elements of the installation phase: they warrant careful attention from the Project management team.

RF Systems The Main Linac Cryomodule (MLC) performed well during the FAT and demonstrated an energy gain of 53 MeV, 50% beyond the nominal 36 MeV. This level of performance is highly beneficial since it permits an accurate first turn energy scan as performed in the FAT. The MLC was found to have a +5.5 mm average vertical offset with a 1.5 mm spread cavity-to-cavity. Only about half of this systematic cavity offset can be accounted for. In principle, the average offset can be compensated by an ad-hoc cryomodule repositioning but given the uncertainty surrounding this result the Committee feels it would be beneficial to develop an overall alignment strategy for the MLC taking into account potential HOM modes. The intra-cavity alignment is within tolerance. The MLC field stability was not measured due to LLRF issues.

The issue of microphonics in the MLC was discussed during the last review and significant progress has been made in mitigating its effects. Vibrations from thermoacoustic oscillations and valve actuators have been addressed. There remain 8 Hz vibrations from the vacuum skids and a less well understood 59 Hz signal that needs investigating and damping. There is a concern that MLC HOM absorbers have very little heat handling margin at full beam current.

The Injection Cryomodule (ICM) produced the required 6 MeV beam energy though cavity 2 cannot be tuned to the CBETA operating frequency of 1.2999 GHz and was turned off. This resulted in a ~15% emittance growth in the FAT. The operation of this cavity off-resonance needs careful evaluation since it may result in dangerous conditions for the RF input coupler. The ICM is not ruled out as the source of the observed beam jitter (other possible sources are the laser and PS instabilities), although the specification of the energy stability of the individual cavities are sufficient for ERL operation.

Only one out of three 5 kW, and one out of three 10 kW SSA amplifiers performed as required. The SSA issues are understood although the repair of the damaged RF isolator ferrite plates will not be complete until January 2019.

Instrumentation The BPM system performed well in the FAT. The linear and nonlinear responses were measured and they were used to observe the orbit response to magnet kicks and dispersion. Precision measurement of beam position will require calibration that incorporates their nonlinear response. All 160 BPM electronics boards have been assembled, and 100 have been successfully commissioned. The complete system is expected to be ready for the first beam operation. Other instrumentation (viewscreens, fast and slow Beam Loss Monitors (BLMs)) were also successfully operated in the FAT. Some electronics (the new 41.9 MHz laser synch system, pattern generator, BPM trigger fan-out, …) still have to be designed and built. While it is not clear if everything will be done in time, the old 50 MHz laser system can be used for the initial beam operation.

BLMs are part of the MPS (Machine Protection System), and work remains to fully integrate them in the MPS. The BPMs are presently not part of the MPS except for BPMs in the dump line.

In view of the anticipated sensitivity of the permanent magnets to radiation damage great care will be necessary to ensure that BLM inhibit thresholds are set correctly to give adequate protection from equipment damage. The

Committee suggests that the Project have an in-depth review of the Machine Protection System including the commissioning plan and calibration of beam loss monitors.

Installation and Infrastructure The Town of Ithaca regulatory compliance has delayed installation of infrastructure (power distribution and equipment platforms). The building code issues have now been resolved. The historic unnecessarily high hazard rating for the lab has been reclassified to something more consistent with the lab's role. With recent completion of the installation of CHESS-U magnet girders, reconfiguration of the space for the return arcs is now underway. Installation of radiation shielding will begin mid-October. The northeast equipment platform is scheduled to be in place by November 23. Facility upgrades (water and power) are now underway.

A safety plan is being developed with an internal review scheduled for December 1 to be followed by University review and an operating permit by mid-January 2019. Magnet girder installation will start at the beginning of November and a detailed choreography for the complete accelerator installation consistent with the milestone 8 schedule has been developed. The Committee notes that courtesy of the FAT, the injection system and the MLC is already installed and commissioned. Nonetheless, there remains little margin for error at this point and major holidays (Thanksgiving and Christmas) are unhelpful in this regard.

3) Charge #3: ***Beam commissioning:*** *planning, risk analysis, and contingencies.*

Response: *The Project outlined in broad terms a commissioning strategy and a plan for the more detailed operation. The FAT results and the healthy energy overhead in the MLC provide an excellent basis for the start of the commissioning process. Contingencies involving 2- and 3-pass operation were described.*

The Advisory Committee was pleased to hear that the CBETA commissioning can rely on an electronic logbook and the same operation team configuration as has been used for the FAT [e.g. one shift leader, support for operation and controls and up to 4 technical personnel and collaborations for technical support]. This seems to be adequate and sufficient for the CBETA commissioning.

The Advisory Committee was however concerned about the apparently low attention that was given to Machine Protection and Radiation Losses in the commissioning plan. Given the potential sensitivity of the permanent magnets to radiation damage, the Committee felt that more priority should be given to losses during the machine commissioning, including appropriate training for the operating crew. Enhanced analysis of the sensitivity of the magnets to radiation damage and the ability of the loss monitors to protect from such levels would seem prudent.

The Committee learned that setting up the ERL configuration including the relativistic corrections requires the adjustment of 16 parameters with 14 constraints. It was not clear from the presentations that all constraints were actually orthogonally independent and not degenerate. The committee feels therefore that this setup might be challenging during the commissioning and suggests establishing the required tools and measurement procedures in due time before the commissioning, testing them with the virtual machine configuration.

It was not clear from the presentations at what stage the operation team would switch from the baseline, 4-pass energy recovery configuration to the back-up scenarios with 2 or 3 passes. The committee suggests defining and spelling out the criteria and deadline for taking these decisions well before the commissioning starts.

4) **Charge #4:** ***Response to recommendations:*** *from the February 2018 Advisory Committee meeting.*

Response: *The Project provided clear responses to the recommendations from the last meeting. By and large, the Project was receptive to these comments and had reacted to most of the Committee's suggestions in an effective manner.*

One area of continuing concern was that of instrumentation. The Committee continues to believe that achieving high current operation will require additional instrumentation. While not disagreeing with this observation the Project indicated that it was not possible, for both financial and logistical reasons, to enhance the CBETA equipment baseline at this time. The Project is pursuing a strategy to secure both additional funding and collaborators for CBETA operations beyond the commissioning phase to address these issues. The Committee encourages these efforts.

Appendix 1 – Meeting Agenda

CBETA Advisory Committee meeting, October 8 2018 - AGENDA v7

Panelists: Mike Harrison (BNL) chair, Sergey Belomestnykh (FNAL), Oliver Bruning (CERN), Wolfram Fischer (BNL), Shinji Machida (RAL), Dave Rubin (CU).

			Charge #			
Thursday, February 22, 2018			1	2	3	4
8:30	Welcome, organization	Julia Thom	x	x	x	x
8:35	Project status	Steve Peggs	x			
8:55	FAT technical report	Colwyn Gulliford		x		
9:15	Lattice status	Scott Berg		x		
9:35	RF Systems	Peter Quigley		x		
9:55	Instrumentation	John Dobbins		x		
10:15	**COFFEE BREAK**					
10:30	Splitter	David Burke		x		
10:50	Halbach magnets and girders	Joe Tuozzolo		x		
11:10	Installation and infrastructure	Rich Gallagher		x		
11:30	Commissioning planning	Georg Hoffstaetter			x	
11:50	Resource limitations to completion	Karl Smolenski			x	
12:10	**LUNCH BREAK**					
12:40	Executive session	Committee members				
14:00	Close-out	Sub-committee leads				
14:30	**ADJOURN**					

Charge number key:

1 Fractional Arc Test
2 Technical readiness
3 Beam commissioning
4 Response to recommendations

Appendix 2 – Committee Charge

Date: August 20, 2018

To: CBETA Advisory Committee

From: Berndt Mueller, Chair of the CBETA Oversight Board

Subject: Charge for the Advisory Committee meeting on October 8, 2018

The next meeting of the CBETA Advisory Committee will take place by teleconference on the morning of October 8, 2018. The Committee is asked to report to the CBETA Oversight Board on whether the project will be able to deliver the parameters listed in Table 1, on a schedule with the high-level technical milestones shown in Table 2, and to offer advice on ways that the probability of technical success can be maximized.

There will be no opportunities for real-time executive sessions by the Advisory Committee during the teleconference, and so the close-out presentation by the AC at the end of the meeting will be limited to personal remarks from the committee members. Please make a written report available to the CBETA Oversight Board by October 31.

Please comment on the presentations that will report on:

1. **Fractional Arc Test:** technical successes, hardware performance, results achieved, and lessons learned.

2. **Technical readiness:** (Halbach girders, splitters, RF, et cetera). Delivery status, issues, and installation readiness in the intensive construction period leading up to technical milestones 7 and 8 (“Girder production run complete” and “Final assembly and pre-beam commissioning complete”).

3. **Beam commissioning:** planning, risk analysis, and contingencies.

4. **Response to recommendations:** from the February 2018 Advisory Committee meeting.