Report of the CBETA Advisory Committee

January 30-31, 2017, Ithaca, NY

Committee Members

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

Format

The review consisted of a day and a half of plenary sessions followed by a short Q/A session and the preparation of the Committee's close-out. The meeting agenda is given in Appendix 1.

The Committee charge for the review is given in Appendix 2. There was one general question to the Committee together with three specific charge questions. The Committee's responses to the specific charge elements are given below together with a short comment section which captures the Committee's reaction from the discussions of these specific charge items.

Response to the Charge

The Committee is asked to review whether "**the design of the project will be able to support the design performance and whether the engineering design of the project, including all technical subsystems, is sufficiently complete to proceed to detailed designs and start of construction**".

Response: *The Committee believes that the baseline design as described in the design report is consistent with both the KPP and the UPP parameter sets.*

The engineering design is sufficiently mature to warrant the start of construction activities. However we believe that further design iterations (e.g. system integration, value engineering) and more detailed engineering specifications will be beneficial in several areas (survey, BPM resolution).

In particular:

Does a baseline parameter set and lattice layout exist?

Response: *The design report does contain a series of tables which specify the baseline parameters for both the single and four-turn scenarios. The lattice is well defined as evidenced by the simulation results such as orbit correction and beta-beat evaluation.*

Comments: *It would be nice to see a complete loop for the tolerance / specifications discussion (alignment, temperature versus number and strength of the corrector elements) that demonstrates that the most cost effective solution has been adopted and, for example, answer the question if one could reduce the number of corrector magnets if the alignment tolerances are set tighter.*

We would recommend to include the space reservations for the diagnostics boxes in the splitter section from the beginning on and to mark the required space for these items in the layout drawings.

We would recommend preparing a simulation tool for testing the LLRF system in multi-turn ERL operation mode. The CBETA operation requires operation with high current bunches at very different energies passing simultaneously through the MLC. This operation mode can probably not be simply scaled from normal LLRF systems and past operational experience with the MLC. Such a simulation tool would certainly help in achieving the transition from single turn to multi-turn ERL operation within the targeted period of 3 month.

It would be nice to see a more complete discussion on the maximum expected beta-beat for the uncorrected quadrupole errors in the machine for different installation scenarios (e.g. random versus sorting) and to see how this evaluation translates into maximum acceptable magnet field errors.

It would be nice to see a thorough robustness study (e.g. orbit and optics function range for various field errors and magnet alignment error implementations and with BPM errors) to define the minimum required alignment tolerances with the expected BPM accuracies.

There could be another very interesting test program based on single turn ERL operation with high current (up to 140mA to 200mA!) that is not strictly speaking part of the NYSERDA program. However, it might be useful to define early on the desired parameter range for such an auxiliary program to see if that all accelerator components are compatible with it.

A concern might be the momentum acceptance of the FFAG at the low momentum end. In the present lattice, transverse tunes reach a half integer quickly below the design energy of 42 MeV and the momentum acceptance of the FFAG arc could be a problem in case the energy gain in the MLC turns out to *be (temporarily) limited to below 36MeV during the CBETA commissioning. Such a situation would benefit from some flexibility in the lattice parameters, especially tune vs momentum and time of flight vs momentum. Since the main lattice consists of permanent magnets, the transverse tunes can be adjusted only via correction elements. It would be interesting to explore the flexibility of the present lattice parameters, e.g. tune vs momentum and tof vs momentum, as a function of the correction circuits.*

At the time of the review, the review committee did not see a detailed description of the different steps that are required for the 4-step commissioning of the splitter: from a single pass operation, to a 1 pass ERL mode operation (implying an RF phase advance of an odd multiples of π between each passage of the MLC), to a 4 pass re-circulating linac operation mode (implying an RF phase advance of multiples of 2π between each passage of the MLC), and finally to a 4 pass ERL operation mode (implying an RF phase advance of multiples of 2π between the first passages of the MLC and a phase advance of π between the 4^{th} and 5^{th} passage of the MLC). It is not clear how the path length of the splitter is adjusted by half an RF wave length between the different commissioning steps and if these adjustments are accumulative and to what extent the tuning method established at one step would still be valid at the next step?

During the review, it was stated that the mechanical arrangement of the path length shifter does in principle not require transverse displacements. Is this also true for the transitions between the four commissioning steps of the splitter?

Simulation of orbit correction demonstrates that it is possible to correct the orbit with the assumed diagnostics, which means the orbit is well under control. However, it was not clear from the review how the lattice and twiss parameters such as dispersion function, optic functions and (local) phase advance can be measured experimentally during the CBETA commissioning. The beam line of the CBETA lattice is not a periodic system although one may be able to make an assumption of local periodicity for some measurements. It would certainly be useful to define already at this early stage 'how' and with 'what accuracy' these parameters can be measured at each commissioning stage with the available diagnostics system.

A beam goes only 4 (8) turns in the CBETA lattice. A complete beam tracking with an online model should therefore be possible with a direct link to the EPICS database that stores the current settings of the machine hardware. At the early commissioning stage with beams of the KPP specifications intensity dependent effects should be negligible (except perhaps in the injector). A staged approach of developing an online model is recommended, starting from a simple single particle tracing based on the detailed hardware parameters to the stage with intensity dependent effects using multi-particles for the beam modeling when the intensity is being increased.

Errors in the total path length are the sum of the orbit errors in each section: FFAG arc, transition section, straight section, and splitter. For the ERL and re-circulating linac operational purpose, the total path length is the only figure which needs to be measured and corrected. However, the distributed BAMs make it possible to measure the path length in each section locally. Information on the sensitivity of the path length on orbit errors in each section (by simulation) would be useful for the machine tuning during the commissioning.

BBU threshold has been shown as a function of phase advance. Phase advance of non-scaling FFAGs strongly depends on momentum especially at the low momentum end. Therefore, an operation with a slightly different energy gain in the MLC could possibly cure BBU. On the other hand, it is important to estimate momentum jitter and its effects on BBU as well. It might become difficult to identify a cause of BBU when the phase advance is not stable from pulse to pulse due to momentum jitter.

Are the specifications for the four-pass ERL as well as all technical subsystems complete?

Response: *As previously stated the physics specifications for the four-pass ERL are determined. The technical subsystems are sufficiently well defined to proceed on the upcoming procurements to reach the next series of milestones. A more comprehensive set of technical specifications and drawings will be required for many subsystems to proceed through procurement and fabrication to initial operation.*

Committee Comments: *The assembly of the Halbach magnets requires sorting of magnet blocks into magnets. To achieve the required field strength and quality, some magnet blocks may need to be rejected. The total order size (i.e. blocks that will be used in magnets and excess blocks) should be based on an explicit assumption of the distribution width for the block strength. This explicit assumption should be based on empirical data and other estimating tools.*

The assembly and disassembly of the Halbach magnets was not presented at the review, and the proof-of-principle magnets could not be split. Even the magnets that can be split need to maintain field strength and quality, and the assembly and disassembly needs to be done safely.

The baseline design of the straight section requires significant and different strength shimming of magnets. This creates a problem as spare magnets could not be pre-shimmed ahead of time. Thus, the capability of magnetic measurement and shimming needs to be maintained throughout the CBETA operating time in order to expediently replace a magnet if necessary.

The required resolution of path length measurement and adjustment does not seem to be completely determined, and needs to be specified.

The splitter-combiners have numerous magnets in close proximity to each other. The cross-talk between all splitter-combiner magnets has not been investigated yet, which is required for a proper functioning of the splitter-combiners.

Orbit corrections simulations were done without BPM errors. This is easily correctable and will give a more realistic simulation.

Orbit correction schemes with a reduced number of correctors (e.g. half) could provide guidance for scope reduction.

Experience has shown that mechanical noise from water pumps, AC, and the Kinney pumps may interfere with operation, especially of the cryomodule. This should be properly evaluated, and mitigation measures may be necessary.

Large microphonic noise on the unstiffened cavities in the MLC is a concern for stable operation of CBETA. A plan needs to be devised to mitigate this noise.

The margin on the HOM power in MLC was not presented. A small margin can limit certain operational modes.

The types, numbers, and location of beam loss monitors is not yet finalized. This is necessary for both operation, and the final design of the machine protection system.

Adding passive insulation near the roll-up door may improve the temperature stability in the CBETA hall. This can be a relatively inexpensive measure providing overall stability to the CBETA systems.

To complete the requirement for the electrical infrastructure, final design specification from several systems (magnet power supplies, beamline components, instrumentation and control, RF high-power amplifiers, pump skids, lighting and outlets, AC and ventilation, metering) are needed.

The MPS design was based on the melting temperature of the beam pipe. A more conservative approach is to base the MPS design on yield strength temperature rather melting temperature.

Do engineering designs for the major components exist?

Response: *We note several significant components exist already (Gun, ICM, MLC, dump, diagnostic line). Major components including FFAG magnets, BPM electronics and controls have engineering designs. Girders, splitters, vacuum and other subsystems are still somewhat conceptual in places.*

Committee Comments: *We note that many of the major components of the CBETA accelerator already exist, have been tested, and are already in place including DC gun, injector cryomodule, and injector diagnostic beam line. The main linac cryomodule has been tested without beam and has been moved into position in the hall. Designs for the all the remaining major components exist, although some are rather conceptual.*

While designs for the major components exist, some are very new. Designs for splitter combiner support structure as well as arc girders would likely be beneficially refined with a round of critical value engineering. The splitter/combiner regions are especially crowded with magnets and related infrastructure. Drawings that include all components, such as cables and routing, cooling water lines, beam instrumentation, should be completed to demonstrate a practical solution and necessary accessibility for both assembly and maintenance.

The recent decision to use Halbach magnets in the FFAG arcs rather than the hybrid design, requires re-evaluation of alignment of magnets on girders. The re-optimization should be completed very soon so that final alignment of magnets on girders can be specified.

The radiation shielding calculations should include fault studies. Where, for example is the beam lost if there is a vacuum burst at the cathode, or if one of the injector or main linac cavities trips? Such a study would help guide the deployment of shielding, and vulnerable equipment. The Project should evaluate effect of radiation on magnet field quality in order to establish tolerance to beam loss.

The accelerator physics team has developed a detailed model of the ring that has been used to optimize the design of the guide field optics and explore dependencies. The tracking study of misalignment tolerance indicates that the number and location of corrector magnets in the design lattice are sufficient to compensate survey misalignment at the level of 200 microns, assuming that the beam position monitors have perfect resolution. We recommend that the study be extended to include field errors and realistic BPM resolution. Indeed such a study is essential in order to specify; survey tolerance, BPM resolution, field quality and stability.

The committee was concerned that vibrations from the very large water pumps located inside the ring, adjacent to splitter section and very near to the main linac cryomodule will complicate operation and compromise performance. We note that the high Q RF cavities are especially sensitive to microphonics.

The Halbach style FFAG magnets have been designed. Similar magnets have been built and tested for other projects, thus demonstrating the viability of the design. However, it is important that first article prototypes be built to the cBeta design specifications. The CBETA design requires that the magnets be split for installation. This feature, along with the standard magnetic properties must be demonstrated.

Splitter and combiner magnets are all electro-magnets. The design of the splitter/combiner magnets should be finalized, that is coils as well as laminations, so that power supplies can be specified and distribution of electrical power and cooling water requirements can be established.

Appendix 1: Agenda

CBETA Advisory Committee Technical Review - AGENDA

Cornell University, Wilson Laboratory, Room 374.

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

Monday, January 30, 2017

8:30	Executive session	
9:00	Project status	Steve Peggs
9:30	KPP & UPP strategy	Georg Hoffstaetter
10:00	Baseline lattice & studies	Chris Mayes
10:30	Engineering status	Karl Smolenski
11:00	**BREAK**	
11:15	FFAG magnet requirements & specifications	Stephen Brooks
11:45	FFAG magnets & girders	Joe Tuozzolo
12:15	**LUNCH (in-situ)**	
13:00	Splitter-combiners	David Burke
13:30	Transitioning between FFAG arcs	Scott Berg
14:00	DC injector & space charge simulations	Colwyn Gulliford
14:30	BBU simulations	William Lou
15:00	**BREAK**	
15:15	Main Linac Cryomodule & LLRF	Fumio Furuta
15:45	Vacuum system & beam stop	Yulin Li
16:15	Power supplies	John Barley
16:45	Executive session	

Tuesday, January 31, 2017

8:30	Beam commissioning	Adam Bartnik
9:00	Controls, instrumentation & machine protection	John Dobbins
9:30	Shielding & radiation safety	Brian Heltsley
10:00	System integration	Rich Gallagher
10:30	Homework responses	
11:00	**BREAK**	
11:30	Executive session (lunch provided)	
15:00	Close-out	

Appendix 2: Committee Charge

Charge for CBETA Technical Baseline Review on January 30 – 31, 2017

The CBETA project aims to build a four-pass Energy Recovery Linac (ERL) with a maximum energy of 150 MeV and beam current of 40 mA. A single Fixed Field Alternating Gradient (FFAG) beam line with permanent magnets will be used to recirculate all beams with four different energies.

The Committee is asked to review whether the design of the project will be able to support the design performance and whether the engineering design of the project, including all technical subsystems, is sufficiently complete to proceed to detailed designs and start of construction. This is also the first milestone referred to in the "Statement of Work" attachment to the contract with NYSERDA.

In particular:

- Does a baseline parameter set and lattice layout exist?
- Are the specifications for the four-pass ERL as well as all technical subsystems complete?
- Do engineering drawings for the major components exist?

Please submit a review report addressing these charge elements to Dr. Berndt Mueller by February 15, 2017.