Report of the Committee from the Layout Review for the Cornell-BNL ERL Test Accelerator

June 15 – 16, 2016, Cornell University

Committee Members

Mike Harrison (Chair), Sergey Belomestnykh, Don Hartill, Shinji Machida, George Neil, Vadim Ptitsyn, Dave Rice, David Rubin, Ferdinand Willeke.

Agenda

The complete agenda is given in Appendix 1. The review consisted of an opening plenary followed by parallel sessions on the topics of design, technology and management. The second day was used for a Q/A session and preparing the Committee's close-out.

Response to the Charge

There were four charge elements. The Committee's responses are interspersed below.

a) Review the draft CDR before the meeting and comment what parts of the CDR need more work before the layout parameters of the accelerator can be specified sufficiently to start engineering designs.

The CDR is relatively complete and forms the basis of the machine design and layout. The Committee's comments are as follows: there is no mention of machine protection. Some of the beam dynamics sections are planning rather than design information. Some of the sections are dated. The radiation shielding calculations lack specificity. The CDR needs a more mature commissioning scenario.

b) Review the beam simulations that underlie the accelerator layout. Are the simulations solid enough to define the main parameters of the layout?

The answer is a qualified yes. The basic lattice is well defined which specifies the geometric layout. There were some concerns regarding radiation shielding which could conceivably affect the layout. Simulations are underway but are not far enough along yet to establish: tolerances, magnet alignment, magnetic field quality, splitter layout, path length flexibility, apertures, and instrumentation requirements.

c) Review the main technical choices, including the permanent magnet technology and girders, the vacuum system, and the diagnostic system. Are the choices sound and have major risks been identified?

The major choices of technology and the design choices, in particular the ones for magnets and vacuum, appear to be reasonable. The choice of hybrid magnets offer a number of measures of how to deal with field quality issues at the expense of increased magnet interference and larger magnet dimensions. The compromises made with these respects appear to be reasonable and defensible.

The team is apparently aware of the implications and the risks associated with these choices.

d) Review the timeline of the project and identify major risks for delays.

The timeline is in a very preliminary stage with beam dynamics simulations determining the evolution of the engineering design of the magnets. The procurement of the magnets for the splitter sections and the FFAG are on the critical path. The cost and schedule review currently scheduled for September will require a major update of the project timeline. This should include a detailed set of milestones suitable for use in monitoring progress.

The major risks at this time revolve around the magnet schedule and beam monitoring designs. The other area of concern is the dynamic nature of the funding scenario for the Project.

Accelerator Design

The basic FFAG lattice is well defined. Realistic merger/splitter sectors have yet to be finalized. Simulations are planned and/or already underway to establish tolerances on magnet alignment, magnet field quality, splitter/merger layout, path length flexibility, apertures, and instrumentation requirements (such as BPM absolute accuracy and differential resolution.

Multiple single particle tracking codes are being used to investigate various aspects of the design. The guide field magnets are represented in some codes by maps that include fringe fields and in others with hard edged-models empirically tuned for consistency with the maps. Where comparisons have been made, the different codes are in good agreement. Tracking through the FFAG arcs has been used to establish beta-functions, dispersion, phase advance, and time of flight. Single particle tracking is the basis for determining acceptance of the arcs, sensitivity to resonances, and the effect of misalignment of the FFAG quadrupoles. Characterization of merger sections and the long straight is in flux as the optical design for those components is incomplete.

The committee was presented with a list of simulation tasks and an estimate of the effort required to complete them. The committee generally agreed with that estimate.

The committee comments on the studies that were described in presentations or the CDR are as follows:

MBBU - Multi-pass beam breakup (MBBU) simulations using realistic values of random cavity shape errors have been done for different number of passes. The predicted threshold current is very large for 1-pass but drops close to the level of design current for 4-passes.

The committee noted that experimental studies of MBBU is one of the main objectives of the cBeta test facility and that the exploration of the dependence of MBBU threshold on betatron phase advance, transverse coupling, and *chromatic tune spread should continue with simulations. The committee recommends that the simulation results should be used to determine what additional hardware capabilities are required to perform the experimental MBBU studies at cBeta. (i.e. skew quads, corrector quadrupoles, sextupoles …?)*

HALO - In view of high beam power circulating in the cBeta ERLs, slow (continuous) beam loss presents a serious operational challenge and may limit the achievable beam current. Contributions to halo that have already been studied in cBeta include the injector halo (including space charge) and beam-gas scattering (important, but evidently not a dominate source),

The committee recommends that as machine configuration, parameters and lattice matures, it will be important for the cBeta design team to make advances in understanding all sources contributing to beam halo including contributions from Touschek scattering, main linac dark currents, and *beam transport errors. Halo transport studies should continue to be used to map possible locations of the beam losses and to confirm that presently assumed magnet apertures are adequate. Consider recent successful experience with the collimation system in KEK cERL (reports at IPAC'16) to assess if collimation can be effective for the control of the injector halo in cBeta.*

WAKEFIELDS - Energy loss/energy spread from resistive wall and surface roughness have been evaluated and found to be at a level of ~100 keV, small but not entirely negligible.

The committee recommends evaluation of other sources of wakefields such as: cavity wakes, and BPMs, and to explore the effects of energy loss/spread introduced by combination of all these wakes onto longitudinal start-to-end transport using BMAD simulations.

Coherent Synchrotron Radiation (CSR) and SPACE CHARGE - Results of initial CSR evaluation using analytical studies and BMAD simulations have been reported. The vacuum chamber shielding was found to produce only moderate reduction on CSR wakes. (The resulting energy loss/spread is of the order of several tens keV.) Simulation of beam transport with space charge has been completed through the injector and the first 42 MeV recirculation pass using GPT and BMAD simulations. MOGA optimization of the injector lattice elements has been demonstrated an efficient strategy for understanding and optimizing performance of space charge dominated beam transport in the injector.

The committee recommends further detailed CSR and space charge studies that include evaluation of microbunching, the effect of induced energy loss/energy spread (mostly from CSR) and beam halo (from space charge) on the start-to-end beam transport.

IONS - Ion accumulation has been observed in the injector. No detailed studies for ion effects on electron beam have yet been done specific to CBeta. As a remedy against the ion accumulation the use of voltage on button BPMs for ion clearing as well as installation of dedicated clearing electrodes are being considered.

The committee recommends simulation of electron-ion effects in CBeta to better understand implications of ion accumulation. Simulations should take into account the non-linear space charge field of electron beam and the spread of the multiple electrons in the FFAG beamline (note: a fast ion instability code for FFAG line is available in BNL). On the basis of studies a required configuration (in terms of number and locations) of clearing electrodes should be established.

More Recommendations

The committee recommends that the cBeta team perform simulations in order to demonstrate the capability of the planned instrumentation (magnets, correctors, beam diagnostics, and controls) to

1. Measure orbits of beams of different momenta, especially through the adiabatic transition sections.
2. Measure lattice functions like beta and phase advance per cell?
3. Distinguish mis-matching of orbit and optics at transition from merge to arc the entrance of beam from FFAG guide field errors? (especially in view of ambiguity in identifying the low energy orbit.
4. Measure the energy dependence of the acceptance.
5. Measure the energy dependence of the time of flight?

The cBeta team should demonstrate with simulation an effective algorithm for correcting orbit and optics given realistic misalignments and measurement tolerances

1. Are the steering corrector magnets properly located.

2. Does the correction algorithm manage the complication that focusing corrections and steering are coupled?
3. Is the algorithm robust?
4. Is there sufficient tunable path length adjustment in the splitters to accommodate alignment errors?

Insofar as the algorithm for measurement and correction of orbit and optics depends on: magnet alignment tolerances, magnet field errors, beam energy errors, BPM absolute and differential measurement error (with single pass measurement of bunch with “low” charge) the simulation should be the source of the specification of the above tolerances.
The two lowest energy orbits are predicted to have very nearly identical trajectories in arcs. A plan for measuring and correcting orbits for all energies should be demonstrated in simulation. We note that understanding the response of the 6 button BPM will likely be challenging. BPM response should be included in simulation

Commissioning

A list of the commissioning items on each part of the machine was presented and discussed. Some initial testing of correction algorithms was demonstrated. The committee heard that an online model was planned.

Planning the machine commissioning is a huge task involving many different skills: beam dynamics modeling, instrumentation, diagnostics and magnet and RF control. It is critical to establish realistic and detailed scenarios of the commissioning from day one and prioritize the measurements which characterize the machine. Fundamental parameters like orbit position and beam profile throughout the beam line should be measured first to ensure stable motion. Software analyzing raw data signals and converting them to physical quantities should be available from day one. High-level software, for example, calculating phase advance from the beam envelope signal with a user-friendly GUI windows, will speed up the commissioning and identify (often trivial) errors in the hardware configuration. Preferably, the commissioning scenarios and procedures will be emulated and checked by an online accelerator model before the real commissioning starts. Realistic online models with practical errors in the alignment of the magnets and limited accuracy of the diagnostics will be a useful tool even after the real machine commissioning starts.

It is a good idea to plan to operate the hardware (in particular the linac) with off-normal settings to help machine characterization studies. For instance, if it is possible to operation linac with slightly different energy gains per turn, then the resulting orbits with slightly different momenta results in a direct measurement of the dispersion function. As another example, reaching the same final energy either with 3 pass of linac or 4 pass of linac (with 3/4 of energy gain per turn) should give the same orbit and optics at the final energy if the correction of the machine is perfect. This will test of the robustness of the correction schemes. Likewise, it would be a good exercise to think about any additional unusual operations which may be able to reveal further machine characteristics.

The Project team mentioned the possibility of commissioning a partial arc. This is a good idea and a similar practice was useful in the EMMA commissioning, not only for beam dynamics measurements, but also for hardware debugging, especially diagnostics. On the other hand, partial arc commissioning takes effort and resources and risks interfering with the ongoing installation tasks. Ultimately it is up to the Project team as to whether it should be included as part of the baseline plan.

In conclusion it should be emphasized that the commissioning strategy of the FFAG beam transport needs careful analysis since the usual strategies adopted with more conventional accelerators may not work. Separation of the ideal orbit and the geometric center of the magnets in the presence of very strong focusing can make it difficult to define a reference orbit; a standard assumption that is not necessarily true in a FFAG transport line.

Technology

Injector

cBeta will use the injector which was developed and commissioned for the Cornell ERL project. The injector has already demonstrated performance (bunch charge, average beam current, emittance) in excess to what will be required for cBeta.

We have identified two areas of possible concerns: The lifetime of the photocathodes and the locations of the laser room with respect to the DC gun.

So far, the required high-average-current operation of the photocathodes was demonstrated on the time scale of one shift or eight hours. The result was a measured lifetime of 2.6 days at a continuous operating current of 65 mA. This is a sufficient demonstration for the required performance operation in R&D mode. However, it appears to be desirable and prudent to perform more studies which should aim at understanding the robustness of the cathode's photoemission layer over a longer time period.

With the injector move to L0E, the laser room location is now about ~600 ft. away from the DC gun. This may result in significant latency for the machine-protection light shutter and could adversely affect laser jitter with respect to the RF field.

Recommendations:

We recommend measuring the cathode lifetime at 40 mA over a period of several days.

We also suggest consideration be given to moving the laser room or at least the machine-protection shutter closer to the injector.

RF systems

The superconducting acceleration structures and the RF systems of the injector and the LINAC have been operational for several years. The performance is quite good and is more than adequate for cBeta operations. In particular, the Main LINAC Cavities and the associated systems were tested and they have demonstrated a performance which has exceeded cBeta requirements. However, there are two areas of concern.

First, cryogenic pump skid is located very close to the cryomodule. Vibration from these pumps could induce microphonic noise generated in the cavities as they could couple to the cold mass through the cryogenic piping or via the floor and the support system. This might lead to RF control issues or even cause a limitation of the cavity gradient due to the limited RF.

Second, while solid-state amplifier technology proved to be a good choice for RF amplifiers as was demonstrated during the MLC testing, there is only limited information available on the reliability of this technology and in particular of the particular implementation which raises a concern.

Recommendations:

We recommend consideration be given to moving the cryogenic pumping away from the vicinity of the accelerator.

We further suggest revisiting the solid-state RF amplifier reliability and considering an alternative vendor.

Magnets

The choice of a hybrid-permanent magnet for the quadrupoles in the FFAG arcs and in the straight section is reasonable and defensible.

The properties of these magnets have been well explored theoretically and fairly accurate models have been worked out as a base for the beam optics design. The overall design considerations (apertures, offsets, etc..) which take into account important considerations of the vacuum chamber design appear to be prudent and reasonable.

A prototype has been built which is close to meeting the expectations though it has not yet reached the envisioned performance. The deficiencies, however, seem to be understood and can be addressed by a reiteration of the design.

At this point, however, there is no clear and unambiguous set of magnet requirements from the point of view of beam dynamics. This is urgently needed to specify the magnet components to be procured from commercial manufactures. The associated tasks and activities are on the critical path as it is a prerequisite for starting the magnet/component procurement process.

The integration of magnets, girders, vacuum system and diagnostic systems is at a very preliminary stage. For example, magnet designers have not been aware of the fact that the assembly fixtures have to be assigned as to allow assembly of the magnets on their girders with the vacuum chamber in place. This requirement may have an impact on some details of the magnet design. Therefore, there is some urgency to move forward with the design of these elements.

The magnet arrangement in the spreader region is very complicated. Together with preliminary design of the magnets, it appears to be desirable to develop a concept for magnet supports. Also, an installation and assembly plan should be developed.

Recommendations:

The requirements on magnet field tolerance and on alignment need to be completed with high priority. These requirements need to be kept under strict configuration control.

An effort needs to be made to study the magnet-vacuum-girder-BPM assembly. The constraints of this assembly need to be well understood and need to be communicated with the various teams working on the magnet, vacuum, and diagnostic systems.

A certain formality in developing and maintaining the requirements on the components is advisable to ensure that all designs are well aligned and consistent.

As being discussed within the team, the production of a second prototype magnet and a corresponding girder prototype appears to be advisable to study mechanical and magnetic magnet interference and to test assembly and alignment fixtures.

The magnet design team should pay attention to mechanical magnet stability. Since the magnet is very short but has fairly large transverse dimension, the magnet yoke may deform under the strong magnetic and gravitational forces. This may affect the field quality and the reproducibility of field quality after de-assembly-reassembly. This also may affect the magnet center and the achievable alignment accuracy.

It might be useful to foresee shimming of the poles to correct for non-systematic field errors due to finite assembly tolerances.

Vacuum

A conceptual layout of the vacuum system has been worked out which is awaiting more detailed information of the magnet and BPM system and girder systems.
The presented choices of the shielded bellow design appear both to be acceptable, but final choices probably depend on more complete design of magnets and girders, which underlines the importance to make progress in the preliminary design of these components.

Recommendations: none

Infrastructure

To meet the required schedule, significant planning has gone into the incorporation of the cBeta layout into the existing facility. Although details of the machine layout are still a work in progress, it appears that appropriate choices have been made to install the machine. Some significant alterations of the building and existing controls, plumbing, etc. are required to accommodate the layout. Overall, the plan appears to hang together. Potential issues have been identified regarding

a) Microphonics from the injector cryogenic vacuum pump coupling to the superconducting cavities through the piping or the floor leading to RF control issues and/or gradient limitations from RF power considerations.
b) Placement of radiation shielding (discussed below).

It is clear that performance of the RF system would be improved if the cryogenic pumping systems could be moved outside the ring; preferably onto a separate concrete pad outside. There does not appear to be sufficient funds to do this change so risks will remain on the stability and beam control. In any case some coupling of vibrations through the cryogenic piping into the cryomodule will occur. We encourage the group to consider ways in which the pumping system can be acoustically isolated, especially in regard to the full cryomodule since the desired loaded Qs in that system are quite high.
There is need for alteration of some non-loadbearing walls and replacement/movement of some controls. This does not appear to be a significant technical hurdle or represent significant schedule risk though scheduling will need to be coordinated with CHESS operations.

Recommendations: Consider moving cryogenic pumping outside the ring.

Diagnostics

The primary consideration for diagnostics has been the determination of the BPM approach and requirements. The choice of BNL V301 modules is a logical choice and likely fits the requirements. The detailed approach for incorporation of these systems has not yet been determined. The remainders of the diagnostic systems are conceptual at this time and have not been finalized. One possible way of how to arrive at appropriate requirements is to decide on a commissioning approach. From the commissioning plan follows what diagnostics systems are needed, what resolution and accuracy of the various diagnostic elements are required, and where the equipment should be ideally located. Once this is well understood, final choices and location of the diagnostic system can be made. The rationale behind this procedure is that if the diagnostics are sufficient to quantify proper beam performance during commissioning they should be more than sufficient to maintain proper performance during normal operation.

The BPM button monitors cannot support ± 1kV which would be required to use them as clearing electrodes to suppress ion effects. Thus planning to bias BPM buttons at high voltage does not seem advisable. Either extra buttons or dedicated clearing electrodes are required. Additional planning is required in this area.

Machine protection systems seem to be very preliminary at this time.

Recommendations: Develop a clearer set of requirements for the diagnostics based on needs of the machine commissioning and performance.

Develop the requirements for an appropriate machine protection system.

Shielding:

The overall requirements for shielding have not been completely determined nor effectively communicated. While it is possible that adequate space exists in the facility for the necessary shielding, it may be true that in a couple of regions special efforts will be required. Areas of concern include near the shielding door and in the User Lab areas because of personnel access. It is desirable that these remain accessible to the general public rather than making them radiation worker limited. In most other site areas public access is not possible or significant shielding from concrete, dirt, etc., already exists. One other possible issue is sky shine through the roof. The responsible engineer doesn't have clear guidelines on loss rates from the project. As a starting point for calculations we suggest assuming the possibility of 1 microampere local loss continuous anywhere (or perhaps 100W beam). This is a level which would eventually open a significant vacuum leak terminating beam operations and therefore is defensible to safety review committees without reliance on other diagnostic systems. If adequate shielding can be provided for this worst case continuous loss then the issue is resolved. Since ability to shield potentially affects the viability of the proposed machine layout this will remain a project risk until resolution.

Recommendations: Choose a defensible factor of beam loss and from that determine required shielding layout to achieve ALARA.

Formulate a shielding policy.

Management and Schedule

The existing Cornell infrastructure is very well leveraged and should be emphasized in future project presentations. The photo-injector and main linac cryomodule are notable in this regard.

The evolving project management plan should be capable of meeting the requirements of all stakeholders. There has been considerable progress recently and it is close to completion. More detail in regard to the roles and responsibilities of the Project Managers and the Principle Investigators is encouraged.

We note that there are external constraints on staff availability at both institutions but especially Cornell. This will require careful integration and planning of cBeta in regard to the ongoing operational programs at both institutions.

We note the importance of the Oversight Board in institutional communication and encourage the Project Office to make this an effective channel, in view of the possibility of resource conflicts.

Considerable pre-project work has been carried out to date. The initial funding stream for the project has now begun. The project will face significant challenges to be completed within the fixed total project cost. In this regard we feel an updated baseline cost estimate is crucial. The upcoming review in September is an opportunity to carry this out.

The key performance parameters presented during the review for CD4 are appropriate for the formal completion of the project.

We note that the results of cBeta could have strong cost implications for eRHIC, but the window of opportunity to use this information is finite. There are many factors which help determine the cBeta schedule but the eRHIC program is an important contributor.

The project technical milestones must be consistent with NYSERDA's milestones for triggering payments.

Recommendations: The Project needs an updated cost estimate and associated schedule.

Appendix 1: Agenda

June 15, 2016

Overview (reviewed by the full committee)

08:30 Executive Session (simple breakfast provided)

09:00 Welcome to the committee (Robert Buhrman)

09:10 CBETA overview (Georg Hoffstaetter)

10:15 Lattice design and beam dynamics (Chris Mayes)

11:00 Break

11:15 Progress in the experimental hall, L0E (Rich Gallagher)

11:45 eRHIC risk items (Dejan Trbojevic)

12:15 Lunch with student reports

a) William Lou – BBU

b) Steven Full – Ions

c) Nilanjan Banerjee – MLC vibrations

13:00 Tour: L0E, laser room, control room. Tour guides: Bruce Dunham and Georg Hoffstaetter. In the labs: Rich Gallagher, Adam Bartnik, John Dobbins.

A) Design (Reviewers: Machida, Ptitsyn, Rubin)

14:00 Details of the optics design (Chris Mayes)

14:30 Benchmarking and simulating the FFAG cell (Stephen Brooks)

14:45 Tolerances and operational experience (David Douglas)

15:15 Space charge (Colwyn Gulliford)

15:45 Break

16:00 Beam dynamics and wake field budget (Chris Mayes)

16:30 Commissioning plan (Adam Bartnik)

B) Technology (Reviewers: Belomestnykh, Neil, Willeke)

14:00 Arc cell and orbits with 3D FFAG magnets (Scott Berg)

14:20 FFAG magnets and correctors (Holger Witte [webex])

14:40 FFAG magnets: design and prototyping (Mike Anerella)

15:00 Vacuum design (Yulin Li)

15:20 MLC commissioning (Fumio Furuta)

15:45 Break

16:00 LLRF (Matthias Liepe)

16:20 Diagnostics and instrumentation (John Dobbins)

16:40 Shielding and radiation control (Val Kostroun)

C) Management (Reviewers: Harrison, Hartill, Rice)

a) Project Management Plan (Steve Peggs)

b) Cost methodology, timeline, and WBS plan (Bruce Dunham)

c) Resource Loaded Schedule (Bruce Dunham)

Wilson Lab

17:00 Executive session

18:00 Questions to the CBETA team by email

June 16, 2016

Wilson Lab

Q&A and Closeout

08:30 CBETA team answers to the committee

09:30 Executive session

12:00 Lunch

13:00 Closeout presentation by the committee

14:00 Adjourn