# cBeta Closeout – Feb 2018



The CBETA project is in contract with NYSERDA to build a four-pass Energy Recovery Linac. The Advisory 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 improved.

*The committee considers that the KPPs are achievable in a time period consistent with the commissioning plan. We believe the most challenging **design** parameter will be the high current which introduces many additional complications. And may well require instrumentation beyond the base line. Realizing the design energy requires establishing four passes in the FFAG which will represent a major technical achievement. The impressive simulations and modeling indicate that the 4 X energy gain can be realized with careful commissioning and orbit and optics correction.*

*The construction and commissioning schedule is plausible, with the biggest uncertainty the delivery of components, especially splitter magnets and girders. The infrastructure for the FAT is presently well advanced with timely completion in the hands of the magnet supplier. The project should continue to stay in close communication with vendors in order to insure timely delivery.*

*The committee is concerned that the instrumentation is somewhat constrained by the density of the component layout. We suggest a review of essential instrumentation requirements and possibilities. The start of the girder installation is a new phase of the project. Communication and consensus among the technical teams is essential to ensure that the effort is well coordinated with attention to such elements as temperature stability, power requirements, assembly sequence, etc.*

**Main Linac Cryomodule:** issues and solutions identified and addressed in the testing that has already been performed with and without beam, including microphonics and the need to reliably accelerate or decelerate the beam by 36 MeV on each pass.

- *Large microphonic noise on the unstiffened cavities in the MLC remains a concern for stable operation of CBETA. Sources of the microphonic noise were identified (thermo-acoustic oscillations, noise from the pumping skid, JT valve actuation). A mitigation plan is in place but still has to be implemented. The expectation is that this will allow to reach an MLC energy gain of 58 MeV. This should provide sufficient margin for reliable operation at 36 MeV.*
- *So far, the MLC cavities were only tested individually since only a single prototype solid state amplifier (SSA) was available. Simultaneous operation of all six cavities with the required field stability and minimum energy gain (36 MeV) still has to be demonstrated.*
- *Infant mortality of components of the just delivered SSAs is a concern. While the amplifiers have been factory tested, the test time was short.*
  ***Recommendation**: Perform an extended test of all six SSAs as soon as possible.*

**Halbach magnets and girders:** magnet quality, arc production, integration and installation, consistent with technical milestones 7 and 8 ("Girder production run complete" and "Final assembly and pre- beam commissioning complete").

- *The committee feels that the prototype girder has validated the fundamental concept of permanent magnets. It is now a proven technical solution. In particular, the committee is impressed by the field shimming, which indicates that a single iteration of tuning will produce the desired results.*
- *All indications suggest that the vendors will meet the production targets and BNL can produce one (or more) girders per week.*
- *So far, all of the components have met their specs (mechanical tolerances, magnetization).*
- *It remains to be demonstrated that alignment will be maintained during shipping from BNL to Cornell. However all indications point that this should not be an issue.*
- *The committee would like to note that for the foreseeable future the girders and magnets will remain on a critical path. The team should pay close attention to the delivery and assembly schedule (speed up production ??)*
- *The team demonstrated that a magnet can be repaired if necessary.*
- *We note that while the vendor for splitter/combiner magnets has a track record in Europe, CBETA has not received any magnets yet. The first set of magnets is critical for the FAT.*

**Commissioning strategy:** milestones 9, 10 and 11, which outline a beam commissioning path that meets the key performance parameters. Alternative commissioning strategies under consideration could be more efficient, and could be implemented after the Fractional Arc Test in early 2018.

- *The Committee does not understand how a single pass factor of 2 energy acceptance is technically achievable. As an alternative strategy, the demonstration of the factor 2 energy acceptance of the FFAG lattice (milestone 9) is proposed after the demonstration of the single pass energy recovery (milestone 10). The Committee disagrees on single pass v's factor of 2.*
- *We agree that the demonstration of the factor 2 energy acceptance can only be achieved with a second pass, which could follow the demonstration of milestone 10.*
- *The new proposal also has the potential for earlier demonstration of the KPPs.*

# This Review: the Charge



- *An energy scan within a small momentum range of a few percent will be necessary during commissioning in order to maximize the beam transmission through the FFAG beam line, and more than 99.9% transmission is needed for the energy recovery mode.*
- *It is difficult to predict and set the energy for the best transmission given that there is a bad tune spot near the 42 MeV MLC output energy, and there are inevitably some gradient errors.*
- *After energy recovery has been achieved, demonstrating the factor 2 in momentum acceptance may require very little effort, once the S-1 beamline has been repositioned, and likely provides more time for the demonstration of 4-pass operation.*
- *Alternative commissioning scenarios should be developed for lower transmission efficiencies. Compared to the ATF test, the CBETA lattice has new optics features such as the adiabatic transition from arcs to straights, and one should be prepared for the unexpected. An energy scan is an obvious tool to investigate transmission problems – the equivalent to a tune scan in ordinary accelerators.*

# This Review: the Charge



**Beam tests and studies:** results of beam tests made during "Injector CryoModule", "Main Linac Cryomodule" and other running periods. Please also evaluate and advise on low and high current beam dynamics studies and simulations designed to inform component design (eg Halbach magnets, instrumentation, impedances) and to prepare for beam commissioning (eg closed orbit correction).

- *Tests performed to date demonstrate that with tuning, the injector delivers beam of sufficient quality for the FAT. We encourage the commissioning team to continue developing functionality of CBETA-v to include analysis of beam response measurements to make optimization of beam parameters more deterministic. The measured and simulated beam profiles still show differences that will likely become important for high intensity operation, in particular the shape and formation of the beam halo. A better understanding of the origin for the beam halo might be desirable for the high beam intensity operation.*

- *We see impressive progress in simulation of dynamics with models that includes field errors and misalignments. The tolerances revealed by the simulations are indeed being used to inform specifications for magnet field errors, temperature stability etc. It is important to include BPM errors in the simulations.*

- *The committee encourages the team to think about potential additional diagnostic tools that could help in understanding the beam dynamics when the operation moves from the low intensity, single pass operation to high intensity operation with multiple re-circulations and energy recovery and in particular a prioritized list of additional beam diagnostics tools that could help in the commissioning effort. This list could be digested and discussed with potential international partners. The committee feels that a more transparent discussion within the project and a common agreement on the prioritization is still missing in this process.*

# International collaboration



**International collaboration:** opportunities for cost-neutral collaboration especially during the NYSERDA CBETA construction phase. Potential later phases might extend the BNL-CU collaboration, and might include additional institutions.

***T**here are several international projects with similar, yet complimentary scope as the CBETA project. The most noteworthy projects in this category include: bERLinPro, a high current single pass ERL which has a similar commissioning schedule as CBETA; PERLE, a planned multi-turn high current facility planned in France which is still in its starting phase; and MESA, as low current multi-turn ERL which is in its construction phase.*

*The Committee recognizes that connections between CBETA and these projects do exist already to some extend, but encourages the CBETA team to strengthen further and perhaps organize these collaborations more formally. The committee is convinced there are many potential benefits from a closer collaboration with international partner laboratories ranging from the exchange of commissioning experience to the exchange and development of diagnostics tools.*

*In the UK the ERL studies are involved in the light source community. There is a strong interest in the UK to participate in the CBETA project in terms of UK-XFEL design which has a high priority within the UK accelerator community. Another part of the UK accelerator community is interested in the full understanding of the accelerator with fixed field magnets, which the UK once spent considerable efforts on in the project EMMA and now considers a similar type of machine as a possible future accelerator for short pulse spallation source after the present ISIS on a rather long time scale. It is clear that the involvement in the CBETA project in the construction and commissioning phase is mutually beneficial and was already established in form of an exchange of staff for a short time period (a few weeks). This should continue and even be extended to more long term involvement in the coming years.*

# International collaboration



***Future Users:*** *The committee recognizes that first steps in search for potential future users for the CBETA facility have started. The committee encourages these steps. A user community could help in obtaining funding for an extended operation of CBETA beyond the achievement of the initial design goals. Starting this process now is extremely timely as a program and funding will need to be identified within the next year or two.*

***Instrumentation and Commissioning:*** *CBETA is a 'first of its kind' machine where one would wish to have the maximum tool set possible at hand to fully study and understand this new type of machine. To this extend it would be interesting to explore options for additional diagnostics tools through international collaborations [e.g. gas curtain monitor developed by University Liverpool for single pass transverse beam profile measurements]. In this context it would be helpful to prepare a prioritized list of tools [e.g. measurement of intra-bunch structures] and to explore possible implementations for such devices with international partners.*

***International Framework:*** *The formation of an international ERL Collaboration Network might be an interesting option for strengthening the international collaboration and identifying a potential user community. Such a setup could also help in attracting additional third party funds for the full exploitation of the CBETA facility. The application for additional operation funds in the framework of the future electron Ion collider development is an excellent initiative in this direction which could be integrated within the formation of an international collaboration framework.*

# Parameters



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 |

# Schedule



Table 2: High level technical milestones.

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