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# CBETA Quarterly Report 9


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Cornell University (CU) and the Brookhaven National Laboratory (BNL) are designing, building and commissioning the Cornell-BNL ERL Test Accelerator (CBETA), a 4-pass, 150 MeV electron Energy Recovery Linac that is a prototype for advanced technology to be used in the future BNL eRHIC accelerator. This Quarterly Report records the progress made in the period November 1, 2018 through January 31, 2019. It describes the project status and communicates future activities and milestones, especially in the next quarter.

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## Executive summary

**Technical milestone 7** ("Girder Production Run Complete"), a primary focus of activities at BNL in November, was achieved on November 21, 9 days early. Attention has now turned to attention turned to milestone 8 ("Final Assembly and Pre-Beam Commissioning").

**Technical milestone 8** will mark the exciting transition to regular beam operations, first focused on establishing a single turn of beam, without energy recovery. There are various challenges to meeting the tight schedule for Milestone 8, scheduled for February 28, but so far there are no show-stoppers. Details of the main challenges can be found below, in the section "Progress towards technical goals and milestones" that starts on page 3.

The last **Halbach girder** plates were shipped from BNL to Cornell in December. Approximately 40% of the table-plate combinations were in place (and partially installed) at the end of January. Vacuum pump-down of the west arc was scheduled for early February.

The **Equipment Protection System** continued to be developed. The readiness of an adequate "stage 1" EPS for initial (low intensity) beam continues to be a modest risk to the timely completion of Milestone 8.

**Electronics rack** installation and wiring was just beginning at the end of January, installing cable trays, utilities, and electrical wiring in the return arc. This remains a modest risk to the timely completion of Milestone 8.

The tight timing of the delivery of **splitter electromagnets** by vendor Elytt delivery remained a modest risk to the timely completion of Milestone 8.

The amendment to the **Radiation Producing Equipment** permit that was presented to the CLASSE safety committee in a November meeting was approved and was forwarded to the Cornell Environment Health and Safety (EHS) office. An operating permit from the EHS office was imminent at the end of January.

**Cost and schedule:** The project is on cost and on schedule.

Figure 1 – Technical milestones. Milestones 4 and 6 (**bold**) are also go/no-go milestones 1 and 2.

| # | Technical milestone | Contract | 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** | **20-Apr-18** | **30-Apr-18** |
| 7 | Girder production run complete | 30-Nov-18 | 21-Nov-18 | 30-Nov-18 |
| 8 | Final assembly & pre-beam commissioning complete | 28-Feb-19 | | 28-Feb-19 |
| 9 | Single pass beam 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 |

## Progress towards technical goals and milestones

### *Project management*

Technical Milestone 7 "Girder Production Run Complete", a primary focus of activities at BNL in November, was achieved on November 21, 9 days early.

We submitted a proposal in response to a Funding Opportunity Announcement released by the Office of High Energy Physics of the Department of Energy, under their U.S.-Japan program. This program funds co-operative activities between U.S. laboratories and the KEK laboratory in Japan, where the compact Energy Recovery Linac (cERL) and several other accelerators are located. The joint proposal by BNL, Cornell and KEK – for a relatively modest sum of about $100k from both the U.S. and Japan – has 3 components:

1) Scientist exchange during beam commissioning of CBETA and cERL

2) Beam halo simulations and studies

3) Cross-development of beam diagnostics

A draft "Equipment Transfer and Use Agreement" document has been transmitted from BNL to Cornell, for technical and legal discussions. An Inventory List is in preparation, to become Appendix 1 of the "Equipment Transfer and Use Agreement" document that is now in discussion between BNL and Cornell.

### *Accelerator physics*

Single pass energy recovery (ER) was defined to be the baseline initial configuration of the splitters. Much useful discussion over November looked at a number of possible strategies for commissioning quickly to 2, 3, and 4-pass ER operations, after 1-pass ER operation is sufficiently developed. The designs for 2-pass and 3-pass ER splitter configurations were completed, as also were the dump line optics. Detailed integration with the engineering team continued into December.

Space charge modeling of the dump line found a very good optical solution. Detailed integration with the engineering team continued into December.

Three technical notes were published on the website, and one was revised.

### *Injector*

The control chassis that was borrowed by BNL for LeREC commissioning was returned to Cornell, and reinstalled. Stands in the merger area were modified to allow for RX splitter installation. The new laser system – operating at a bunch frequency of 42 MHz rather than 50 MHz – was installed and commissioned in December.

### *RF system*

In November Peggs and Smolenski visited the vendor AFT for discussions on the repair of the RF circulators/isolators. The nominal plan is now to send the circulators back to AFT for rebuilding in early July 2019, so that they are repaired before operations resume in August.

Gate valves were installed at both ends of the Main Linac Cryomodule (MLC), allowing it to be moved vertically into a corrected final position. In January the MLC underwent final preparations for the minor re-alignment, to take place in early February. Cryogenic cool-down will start immediately afterwards.

### *Halbach permanent magnets & girders*

Halbach magnets in Ithaca were re-inspected for gaps between magnet halves, in January. Magnets with gaps were returned to their nominal condition, without gaps.

The last Halbach girder plates were shipped from BNL to Cornell in December, and full-scale assembly of girders began, with approximately 40% in place (and partially installed) by the end of January. Vacuum pump-down of the west arc was scheduled for early February.

### *Splitters*

22 air-cooled quadrupole magnets were received in December. 16 motion stages were delivered from vendor ADC in November and December. Additional stainless steel extrusions were ordered, and received in December, to finish the RX splitter and merge lines.

Design work was completed on the 2-pass and 3-pass Energy Recovery configurations, in conjunction with Accelerator Physics. The design details for septa 1 were finished and in-house machining began. The long quadrupole design was completed. The designs of the cable- and water-routing layouts and the re-design of the A3-B1 mount were finished.

The beam dump was installed, to be followed in February by the installation of beamline vacuum chambers and magnets.

Elytt magnets continued to be delivered in January. The tight timing of their delivery remained a modest risk to the timely completion of Milestone 8.

### *Instrumentation and controls*

Development of the beam trajectory correction algorithm and controls software continued and progressed well. MATLAB scripts were finished and underwent testing via the virtual machine. The MOXA serial device servers were prepared and installed.

The Equipment Protection System (EPS) – documentation, hardware, and software – continued to be developed. A first draft of the documentation was discussed by relevant parties from Cornell and BNL in a face-to-face meeting at Cornell in December. The readiness of an adequate “stage 1” EPS for initial (low intensity) beam continues to be a modest risk to the timely completion of Milestone 8.

31 viewscreens are in production after their design was finalized, incorporating lessons learned during the Fractional Arc Test, for example selecting a better lens for view-screen cameras. 16 viewscreens go in the splitter beamlines and 15 in the Fixed Field Arc sections. All have been machined, but some still awaited welding and assembly at the end of January. Viewscreen locations in FA/FB and ZX sections have been prioritized, to make the best use of the viewscreens for beam size measurements.

Beam Arrival Monitor and Beam Loss Monitor (BLM) system hardware arrived in January. BLMs were partially installed at the end of January.

### *Vacuum system*

The flow-controlled pumping system that will be used for venting the FFA vacuum chamber was completed. The two needed turbo pumping stations were completed and became ready for use. Representatives from the vendor SAES visited to update firmware on the vacuum controllers.

Design work on the layout of vacuum instrumentation was completed, in preparation for running cables. The designs of all components of the merger/diagnostics line were completed and went to the machine shop. The cross-pipe for the diagnostics line was manufactured. SX, RX and other vacuum chambers continued to arrive. Almost all were in hand at the end of January.

### *Infrastructure*

The much-delayed HVAC upgrade installation was complete before the end of January. Final versions of the drawings for Halbach girder table tops (survey datum points) were transmitted from BNL to Cornell, in preparation for surveying. Installation of FFA girder tables began in January, when the HVAC installation work on the L0E south wall was complete. FFA beamline assembly began in January, with multiple girder plates in place on the tables at the beginning of February. FFA arc utility installation follows the survey work.

The shielding labyrinth was installed, awaiting only a couple of custom-built blocks before installation can be declared complete. The custom blocks will be placed in the angled section near the L0E garage door.

Magnet temperature stabilization system parts were installed. Utilities continued to be installed in January.

Holes were cut in L0E walls for water system and electrical feed access. The electrical system platform (800 A service) arrived and began to be assembled, with completion in February. Installation of the new cooling water system was completed, although the system was still dry at the end of January. The new water system was installed, but not yet commissioned. Electrical installation work continued. This is a modest risk for the timely completion of Milestone 8.

The layout of electronics racks in the L0E hall was finalized. Rack work and wiring was just beginning, in general, at the end of January. Work continued on installing cable trays, utilities, and electrical wiring in the return arc. This remains a modest risk to the timely completion of Milestone 8.

### *Beam commissioning*

Work continued on commissioning planning, first taking the high-level plan down to fortnightly details, and later down to weekly details, with regular beam operations planned to begin on March 1. Plans were also developed for early (pre-complete machine) “soft commissioning” in late February, passing beam through the Injection CryoModule (ICM), the Main Linac Cryomodule (MLC), and the beam dump line.

### *Safety*

The amendment to the Radiation Producing Equipment permit that was presented to the CLASSE safety committee in a November meeting was approved. The amendment was then sent by CLASSE to the Cornell Environment Health and Safety (EHS) office. An operating permit from the EHS office was imminent at the end of January. A staged review process was defined that permits the allowable daytime operational performance envelope to progressively increase.

The CLASSE safety committee met in December to review a hazard analysis / mitigation plan for CBETA. The safety hazard analysis process continued, with documents prepared for the next meeting of the Cornell EHS office.

The exit signs and emergency lights that are needed for a temporary certificate of occupancy were determined after a walk-through by representatives of the Town of Ithaca. Installation of a fire detection continued through the end of January.

Work continued on resolving how best to communicate the safety aspects associated with handling and maintaining the Halbach permanent magnets. A Standard Operating Procedure document was prepared, describing how they are to be handled.

Radiation badges became required in the CBETA control room and in the L0/L0E floor areas.

## Quarterly cost summary

At of the end of January the project was about 75% complete with a posted Total Project Cost to date of $18.7M. Project expenditures in the quarter are summarized in Figure 3, separately for Cornell and BNL.

**Figure 3 Quarterly cost summary.**

Brookhaven CBETA Quarterly Report
November 1, 2018 – January 31, 2019

| WBS | Title | Labor | M&S | Travel | Other | Total |
|---|---|---|---|---|---|---|
| 1 | Project Management | $74,104.29 | $2,420.33 | $21,417.46 | $0.00 | $97,942.09 |
| 2 | Accelerator Physics | $0.00 | $1,703.06 | $0.00 | $0.00 | $1,703.06 |
| 3 | DC Gun / Injector | $0.00 | $527.50 | $0.00 | $0.00 | $527.50 |
| 4 | RF | $0.00 | $928.84 | $0.00 | $0.00 | $928.84 |
| 5 | FFAG Magnets | $153,701.55 | $383,494.53 | $2,512.06 | $0.00 | $539,708.14 |
| 6 | Splitter / Combiner | $1,566.03 | $6,862.82 | $0.00 | $0.00 | $8,428.85 |
| 7 | Power Supplies | $0.00 | $2,737.01 | $0.00 | $0.00 | $2,737.01 |
| 8 | Controls | $0.00 | $1,567.60 | $0.00 | $0.00 | $1,567.60 |
| 9 | Instrumentation | $108,542.99 | $5,319.89 | $1,293.46 | $0.00 | $115,156.34 |
| 10 | Vacuum | $0.00 | $6,470.41 | $0.00 | $0.00 | $6,470.41 |
| 11 | System Integration | $0.00 | $6,617.17 | $0.00 | $0.00 | $6,617.17 |
| 12 | Commissioning | $0.00 | $451.51 | $0.00 | $0.00 | $451.51 |
| 13 | Safety | $0.00 | $779.05 | $0.00 | $0.00 | $779.05 |
| 14 | Cornell University | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| | Total | $337,914.86 | $419,879.72 | $25,222.98 | $0.00 | $783,017.56 |

Cornell Quarterly Report
November 1, 2018 – January 31, 2019

| WBS | Title | Labor | M&S | Travel | Other | Total |
|---|---|---|---|---|---|---|
| 1 | Project Management | $65,864.98 | $15,277.55 | $9,085.98 | $0.00 | $90,228.51 |
| 2 | Accelerator Physics | $80,868.19 | $3,149.32 | $0.00 | $0.00 | $84,017.51 |
| 3 | DC Gun / Injector | $3,993.11 | $2,349.14 | $0.00 | $0.00 | $6,342.25 |
| 4 | RF | $23,082.20 | $18,915.44 | $0.00 | $0.00 | $41,997.64 |
| 5 | FFAG Magnets | $3,198.09 | $2,686.72 | $0.00 | $0.00 | $5,884.81 |
| 6 | Splitter / Combiner | $136,271.80 | $184,302.59 | $0.00 | $0.00 | $320,574.39 |
| 7 | Power Supplies | $21,253.77 | $140,651.19 | $0.00 | $0.00 | $161,904.96 |
| 8 | Controls | $49,327.03 | $15,940.83 | $0.00 | $0.00 | $65,267.86 |
| 9 | Instrumentation | $40,668.51 | $75,152.32 | $0.00 | $0.00 | $115,820.83 |
| 10 | Vacuum | $153,023.66 | $123,051.34 | $0.00 | $0.00 | $276,075.00 |
| 11 | System Integration | $222,571.74 | $206,072.19 | $0.00 | $1,411.78 | $430,055.71 |
| 12 | Commissioning | $34,046.03 | $0.00 | $0.00 | $0.00 | $34,046.03 |
| 13 | Safety | $31,970.65 | $3,274.36 | $0.00 | $0.00 | $35,245.01 |
| | Total | $866,139.76 | $790,822.99 | $9,085.98 | $1,411.78 | $1,667,460.51 |

### Activities and major procurements in the next quarter, Q10

We are on the verge of the critical and exciting transition from assembly and commissioning without beam to system commissioning with beam.

Q10 includes **milestone 8** ("Final Assembly and Pre-Beam Commissioning") at the end of February. **Milestone 8** marks the transition to system commissioning with beam followed by single turn operation in the Task 9 pursuit of **milestone 9** ("Single Pass Beam Energy Scan"), nominally scheduled for the end of June. Single pass energy recovery comes in Task 10.

During Q10 the permanent magnet girders will all be installed, aligned, and will hold continuous vacuum around a single turn. Shielding will be in place and the safety system will be declared ready, following standard Cornell and CLASSE protocols. The control system will face the task of controlling daily beam operations, even though its full development will continue over months and years, adapting to experience with beam as it is acquired.

Beam instrumentation commissioning and development will follow a staged evolution, as the beam is advanced through splitter S (beamline S1), then around the arc, and finally into the return splitter R (beamline R1), where beam will be stopped

Some Task 8 activities will continue for a short period after Task 9 activities have begun. There is some overlap between these (and other) Tasks in the NYSERDA contract, notwithstanding the implicit assumption that all Tasks are purely sequential.

Splitters S and R will need re-configuration after **milestone 9** is achieved, as we evolve accelerator operations from one-turn energy recovery to two turns, three turns, and finally four turns.

There are no more major procurements to be made.