Submission date: 15 September 2018

CBETA Quarterly Report 7

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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 May 1, 2017 through July 31, 2018. It describes the project status and communicates future activities and milestones, especially in the next quarter.

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Executive summary

Beam commissioning continued until May 18 after **technical milestone 6** ("Perform Fractional Arc Test: beam through the Main Linac Cryomodule and a prototype girder") was achieved on April 20, 2018. The figure below shows excellent agreement between beam measurements and theory for the horizontal and vertical tunes per Halbach cell, up to a maximum total energy of 59 MeV that is significantly larger than the nominal energy of 42 MeV. Attention has now turned towards **milestone 7** ("Girder Production Run Complete"), scheduled for November 30, 2018, and **milestone 8** ("Final Assembly and Pre-Beam Commissioning"), February 28, 2019.

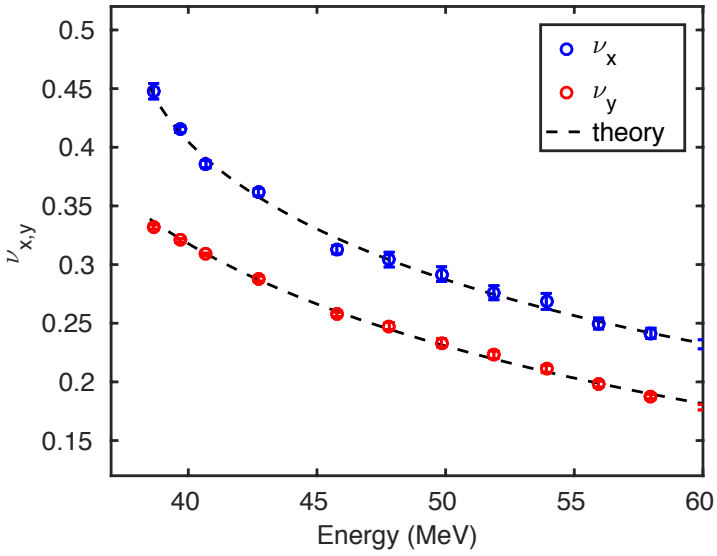

Figure 1 – Technical milestones. Milestones 4 and 6 (**bold**) are also go/no-go milestones 1 and 2.

#	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		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

An "Estimate To Complete" cost and schedule exercise began in May, and continued throughout the quarter, to be completed in August. Simultaneously a second version of the CBETA Cost and Schedule documentation was in development.

Accelerator physics

A Fractional Arc Test (FAT) technical report began to be written by many authors, edited by Colwyn Gulliford. For example, analysis of FAT beam data indicates that the Main Linac Cryomodule (MLC) could need to be vertically realigned. Similarly, beam data indicate an apparent 4% systematic quadrupole strength scaling factor error. A modest splitter magnet field mapping campaign is under consideration, to try to understand the discrepancy.

In May the design lengths of the S-4 and R-4 splitter lines were both increased by a total of one 1.3 GHz wavelength, raising the total harmonic number from 343.5 to 344.5.

Work continued on orbit correction and RF phasing, including the activities of a summer student. Radiation calculations were performed, producing damage estimates and radiation dose limits for Halbach magnets.

Lattice optics design optimization continued, with a number of goals. Injector optics considered the realistic case in which Injector CryoModule cavity 2 is turned off. Although the nominal beam commissioning plan envisages a direct transition from a 1-pass Energy Recovery (ER) configuration to a 4-pass ER configuration, nonetheless 2-pass ER and 3-pass ER configurations are undergoing lattice development as contingencies. The beam-dump line into the optical lattice is the largest remaining (non-urgent) item in preparation for the delivery of a "final" lattice.

Injector

The main focus was on a potential redesign of the line between the Injection CryoModule (ICM) and the MLC, considering the possibility of replacing the existing injector quadrupoles with BNL ERL quads. The laser oscillator was re-designed in order to have better temperature stability. Work began on redesigning the laser RF synchronization sub-system.

RF system

In May the MLC was warmed up to room temperature and the ICM to 80 K to save on electricity and to minimize the impact on the cryogenics systems until they are needed for further beam operations in early 2019. Beamline and insulation vacuums were actively maintained.

An upgraded piezo compensation scheme was developed that includes new high-bandwidth piezo amplifiers, in order to further alleviate microphonics issues. New piezo amplifiers were tested, specified and will be purchased.

Solid State Amplifier (SSA) controls software will be updated by Sigma-Phi staff in September, when they return from summer vacation. One 2 kW SSA module will be replaced by Sigma-Phi, who will also provide one spare RF Driver Module. One spare 2 kW module is already on hand.

Isolators manufactured by AFT were damaged and (stopgap) repaired at Cornell during the Fractional Arc Test, after damage due to incorrect assembly by AFT. Although the isolators worked well enough in the FAT, there was damage to the ferrite tile substrate in the loads. AFT will replace the loads and will provide information on how the isolators are to be repaired at Cornell.

Halbach permanent magnets & girders

In May the Halbach magnet vendor (KYMA) shipped 27 QF, QD, and BD magnets for integration with vacuum chambers onto the girders. The last Halbach magnet should be delivered in the last week in October, based on the latest schedule.

In June Halbach magnet production at KYMA achieved a rate of 2 magnets per day. Production batch magnets in the QF and QD styles continued to be received, measured, tuned and accepted at BNL. The production of the remaining set of BD magnets was approved, based on the evaluation of first production magnets. Two first items in each of the BDT1 and BDT2 series were received and evaluated. These magnets became the highest priority for measurements.

In July BNL received parts to build Girder ZB-02, and shipped girder ZA-01 to Cornell. The rate of measuring and tuning Halbach magnets increased with experience. For example, 15 additional magnets were reviewed and accepted (in early August) during the last 2 week span of this quarterly period.

Splitters

The designs of mechanical mounts for quads, dipoles and vertical correctors being built by Elytt Energy were sent out for production in May, and a small number of additional mounts were designed, including “common” dipole mounts and the “common” dipole vacuum chamber mounts. The mechanical design of the septa magnets (8 total) came close to completion. The design of the H5 magnets (4 total) was finished, based on the H4 magnet design but with a wider and thicker return yolk.

The SX splitter layout and vacuum design was completed and was released to vendors in the Ithaca area for machining. About 1,000 parts for the vacuum and magnet mounts were built or ordered. Space in the L0E hall was cleared for the RX splitter tables and preparations were made to install the table legs and tables in preparation for magnet arrivals.

The RX layout and design was completed and went out to vendors in July. A support post for the Injector CryoModule wave guide support was installed, eliminating an interference with the RX splitter table and magnets. The routing for cables and water was established, including the switchyard chambers, for the R1 beamline.

In June Elytt Energy suffered from a flash flood, which destroyed equipment in their factory. Fortunately no splitter magnets were damaged, and the production capability of the company was only slightly impacted. The flooding damaged only magnetic testing equipment and caused short delays with the manufacturing of lamination stacking and coil winding. The Cornell Project Manager made provisional plans to visit Elytt, to emphasize the urgent need for the common dipole magnets and for enough air-cooled and water-cooled quadrupoles and short dipoles for the 1-pass ER configuration.

A purchase order for the final 14 translation stages for path length adjustment on SX and RX splitter tables was placed.

Instrumentation and controls

The number of view screens to be installed in the permanent magnet girders was established. First article production V301 Bam Position Monitor electronics boards began to arrive in June at BNL and began to be tested. All BPM VME chassis have arrived at BNL. Work continued on the beam loss monitoring system – components were procured and produced.. Video cameras were ordered. Two-frequency Beam Arrival Monitor components were assembled and tested.

A new EPICS archiver was prepared and activated after the MLC warmup was completed. Timing system requirements were refined, and hardware to support the timing system upgrade was identified. Miscellaneous older controls computers were replaced. Basic orbit correction software was tested in the virtual machine simulations, with promising results.

Vacuum system

Significant progress was made this quarter in finishing permanent magnet girder chambers, leak checking them, and shipping from Cornell to BNL. A welding jig plate was developed that is capable of handling the varying angles in the TA and TB section beampipes. All straight beampipes were sent to BNL (6 total), where work proceeded on the ZB girders, and 12 sets of transition girder beampipes were on hand for shipment in May.

Tight co-ordination was developed between Cornell and BNL on schedule and delivery. Similarly, welding time and resources between CBETA and CHESS-U projects were carefully negotiated. A new portable venting and purging system, necessary for Halbach girder and splitter integration, was in construction in Wilson laboratory.

The SX vacuum system achieved 100% completion (designed, detailed and released) except for two common dipole vacuum chambers. Only minor work remained necessary on the RX chamber weldments, taking advantage of the copy design function in CAD. The final splitter tasks that remained are in the merger and beam dump areas.

A purchase order for the SX splitter vacuum chambers was awarded. RX vacuum chambers were sent out to quote with the same company. The common dipole chambers designs were finished, and drawings were completed. There was a one-month delay in the delivery of stainless steel extrusions for the splitter beampipes, due to a broken shroud in the supplier's Turks head equipment. Repair was underway in July, with parts delivery resumption predicted in the second part of September. Splitter components were sent out for production.

Infrastructure

After the FAT the shielding walls were removed in anticipation of installation and construction. An upgraded cooling water system design was developed, and the system integration schedule was modified slightly. Utility design work also continued on improving the electrical supply to the L0E experimental hall. Work on the CBETA hall floor slowed down for the summer in June, while CLASSE personnel focused on the CHESS-U upgrade project (in competition with CBETA for resources).

Beam commissioning

Beam commissioning will resume in Spring 2019.

Safety

The highest cumulative radiation reading throughout the FAT was 4 Rad, on the last Halbach magnet – outside the ring, inches from the beam pipe on the horizontal plane.

In June the Cornell Environmental Health & Safety group did a walkthrough of the CBETA hall. General housekeeping was their main concern.

The GHD engineering firm inspected the CBETA hall as part of the planning process for egress, fire detection, and building code definitions. They visited on two different days and wrote a report that defines specifications to be used by a mechanical engineering firm to design an accessibility-exit plan for the CBETA floor areas in collaboration with the Cornell EH&S fire safety group.

Quarterly cost summary

At of the end of July the project was about 58% complete (based on monthly activity statusing) with a posted Total Project Cost to date of $14.2M. Project expenditures in the quarter are summarized in Figure 3, separately for Cornell and BNL.

Figure 3 Quarterly cost summary.

Quarterly Financial Report from Cornell University, May 1 – July 31, 2018:

WBS	Title	Labor	M&S	Travel	Other	Total
1	Project Management	$145,108.08	$7,332.05	$582.25	$0.00	$153,022.38
2	Accelerator Physics	$36,232.65	$1.16	$0.00	$0.00	$36,233.81
3	DC Gun / Injector	$15,033.12	$19,769.34	$0.00	$0.00	$34,802.46
4	RF	$52,504.98	$22,173.17	$0.00	$0.00	$74,678.15
5	FFAG Magnets	$2,346.14	$45,878.43	$0.00	$0.00	$48,224.57
6	Splitter / Combiner	$75,821.25	$186,729.15	$0.00	$0.00	$262,550.40
7	Power Supplies	$6,773.55	$148,550.18	$0.00	$0.00	$155,323.73
8	Controls	$36,544.98	$366.37	$0.00	$0.00	$36,911.35
9	Instrumentation	$30,474.22	$3,558.10	$0.00	$0.00	$34,032.32
10	Vacuum	$102,123.38	$107,837.93	$0.00	$0.00	$209,961.31
11	System Integration	$140,626.19	$116,282.40	$0.00	$60,887.26	$317,795.85
12	Commissioning	$30,715.20	$0.00	$0.00	$0.00	$30,715.20
13	Safety	$33,420.32	$589.78	$0.00	$0.00	$34,010.10
	Total	$707,724.06	$659,068.06	$582.25	$60,887.26	$1,428,261.63

Quarterly Financial Report from Brookhaven National Lab, May 1 – July 31, 2018:

WBS	Title	Labor	M&S	Travel	Other	Total
1	Project Management	$37,369.86	$3,154.56	$30,907.43	$0.00	$71,431.84
2	Accelerator Physics	$0.00	$932.27	$2,055.48	$0.00	$2,987.75
3	DC Gun / Injector	$0.00	$580.49	$0.00	$0.00	$580.49
4	RF	$0.00	$2,937.59	$0.00	$0.00	$2,937.59
5	FFAG Magnets	$54,810.78	$306,397.68	$0.00	$2,410.12	$363,618.58
6	Splitter / Combiner	$0.00	$5,058.45	$0.00	$0.00	$5,058.45
7	Power Supplies	$0.00	$3,682.99	$0.00	$0.00	$3,682.99
8	Controls	$11,595.17	$678.42	$0.00	$0.00	$12,273.59
9	Instrumentation	$27,737.83	$448,777.49	$0.00	$0.00	$476,515.32
10	Vacuum	$0.00	$4,827.75	$0.00	$0.00	$4,827.75
11	System Integration	$0.00	$8,881.42	$0.00	$0.00	$8,881.42
12	Commissioning	$0.00	$1,212.85	$0.00	$0.00	$1,212.85
13	Safety	$0.00	$910.75	$0.00	$0.00	$910.75
	Total	$131,513.64	$788,032.71	$32,962.91	$2,410.12	$954,919.38

Activities and major procurements in the next quarter

Installation activities for the current reporting quarter slowed down as the radiation shielding was removed and the focus moved to FAT commissioning analysis and material acquisition for the installation of CBETA for February of 2019.

Activities in the upcoming quarter will focus on getting most of the material and equipment on site for installation activities that start in October of 2018. BNL's focus is on completing the production of the magnet assemblies and girders as well as completing the procurement and testing of the BPM and BAM instrumentation modules. Cornell University will focus on completing the infrastructure required to support the start of Beam Commissioning activities in 2019 as well as performing system checks on the Injection and Cryomodule sections of the accelerator. Cornell will also be finalizing materials and equipment needed for the splitter sections as well as beam diagnostics and other supporting accelerator systems.