A Muti-Turn ERL research facility: CBETA

Letter of Interest to Snowmass AF1

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Abstract: The Cornell-BNL ERL Test Accelerator (CBETA) has been operated as the first 4-turn SRF ERL [1]. This accelerator is available and uniquely qualified as a first-rate ERL research facility. We encourage the Snowmass community to evaluate the importance of its research potential and to promote its use for a wide scientific program.

The Cornell-BNL ERL Test Accelerator (CBETA) [2, 3] is the world's first multi-turn particle accelerator that captures the accelerated particles and reuses nearly all of the energy to accelerate new particles. At small current, electrons have been accelerated for four passes through an SRF linac, and have then been decelerated again four times to the injection energy. This Energy Recovery Linac (ERL) has 6 cavities in its 4-turn accelerator. When operating as a 1-turn ERL, each of these cavities recovered 99.5% of the energy of each decelerating electron. CBETA saves Energy by energy recovery in SRF cavities, but also by the use of permanent magnets. These are arranged in the first large energy-aperture Fixed Field Alternating-gradient [4] (FFA) optics so that the 7 beams of the ERL travel in a single beam pipe [5]. This project therefore paves the way for ultra-bright particle accelerators that use far less energy than today's technology and is referred to as a "green accelerator" [6, 7].

The CBETA team reached full 4-turn energy recovery at the end of 2019. While design and construction was achieved by a team from BNL and Cornell, a group of international scientists helped during commissioning, including physicists from JLAB, STFC/UK, HZB/Germany, and KEK/Japan. Since spring 2020, CBETA is in standby mode in an operationally ready state. An experienced operations team is available and the accelerator is now ready to start a first-rate ERL-research program.

These achievements at CBETA are especially relevant and the ERL-research program is especially promising in the light of the increasing importance that ERLs have obtained: ERLs are part of the hadron coolers for the EIC, they are part of the LHeC plans, they are an integral component of an FCC-ee design option, and the European Strategy for Particle Physics has designated ERLs as a technology to be pushed forward. ERLs can also drive low energy nuclear physics experiments, and they have been investigated as drivers for compact Compton-x-ray sources and for industrial lithography.

Important research topics include:

- High-current, high-brightness injector tests.
- CSR and micro-bunching during beam transport for large bunch charges.
- Smooth beam production for hadron cooling ERLs of the EIC.
- Halo of high-current electron beams.
- Beam loading of cavities for different bunch patterns and for the ERL startup scenarios.
- The Beam Breakup (BBU) instability for multi-turn ERLs.
- Beam transport in compact, strongly focusing accelerators with crosstalk between beam lines.
- SRF stabilization with very low-loss cavities, micro-phonics, and multiple beams.
- Beam-orbit and optics correction for multiple beams in the same beam pipe.

CBETA was constructed by the U.S. Department of Energy's (DOE) Brookhaven National Laboratory (BNL) and Cornell University, funded by a 2016-2020 contract of the New York State Energy Research & Development Authority (NYSERDA) with BNL, and it is located on the Cornell campus in Ithaca, NY. The permanent magnets for the FFA arrangement were designed, developed, and precisely tuned at BNL. And the DC-gun and accelerator components had been produced by Cornell under an NSF grant.

In 2014, BNL and Cornell University collaborated to design a multi-turn Energy Recovery Linear-accelerator (ERL) using SRF acceleration and a single beam line made of Fixed Field Alternating-gradient (FFA) permanent magnets. Cornell University had previously constructed and commissioned an electron source, a high-power SRF injector linac, and a high-current SRF linac for ERL operation with funds from the National Science Foundation (NSF) and from industry [8, 9]; these were used in CBETA. Meanwhile, FFA magnets were envisioned at BNL for the EIC; and in 2012, component construction began [10]. Both laboratories have the expertise to spearhead an ERL research program at CBETA.

The CBETA design and experience during operation are already providing significant input into the design of the hadron coolers of the EIC and into the follow-up on the European Strategy for Particle Physics. We encourage the Snowmass process to review and to promote a continued fruitful research program with CBETA.

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