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DISCLAIMER

STATUS OF HIGH CURRENT R&D ENERGY RECOVERY LINAC AT BROOKHAVEN NATIONAL LABORATORY *

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Abstract
An ampere class 20 MeV superconducting Energy Recovery Linac (ERL) is under construction at Brookhaven National Laboratory (BNL) for testing of concepts relevant for high-energy coherent electron cooling and electron-ion colliders. One of the goals is to demonstrate an electron beam with high charge per bunch (~ 5 nC) and low normalized emittance (~ 5 mm-mrad) at an energy of 20 MeV. Flexible lattice of ERL loop provides a test-bed for investigating issues of transverse and longitudinal instabilities, and diagnostics for intense CW e-beam. The superconducting 703 MHz RF photo-injector is considered as an electron source for such a facility. We will start with a straight pass (gun - 5 cell cavity - beam stop) test for the SRF Gun performance studies. Later, we will install and test a novel injection line concept for emittance preservation in a lower energy merger. In this paper we present the status and our plans for construction and commissioning of this facility.

INTRODUCTION

The R&D ERL facility at BNL aims to demonstrate CW operation of ERL with average beam current in the range of 0.1-1 ampere, combined with very high efficiency of energy recovery. The ERL is being installed in one of the spacious bays in Bldg. 912 of the RHIC/AGS complex (Fig. 1). The bay is equipped with an overhead crane. The facility has two service rooms and a shielded ERL cave. Its control room is located outside of the bay in a separate building. The single story house is used for a high voltage power supply for 1 MW klystron. The two-story unit houses a laser room, the CW 1 MW klystron with its accessories, most of the power supplies and electronics.

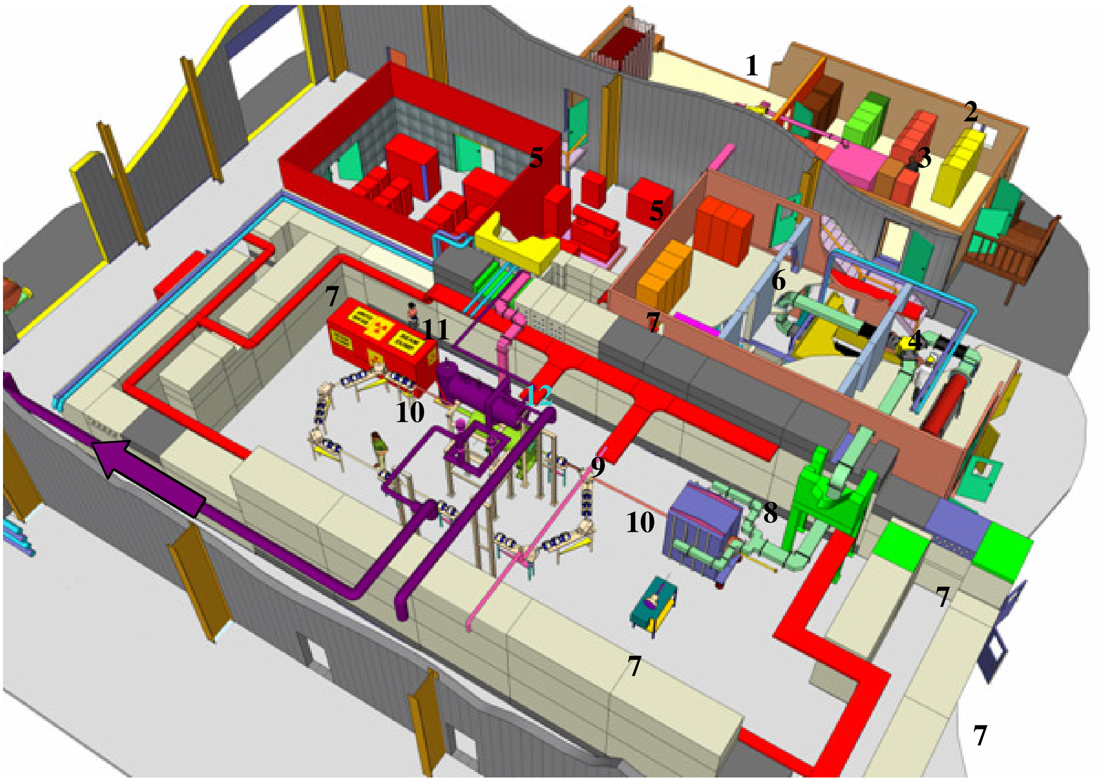

Figure 1: Layout of the R&D energy recovery linac in the shielded vault in bldg 912:1-Control Room; 2-diagnostic and control racks; 3-704 MHz 50 kW CW RF transmitter; 4- 704 MHz 1MW CW klystron; 5- 2MW CW HV power supply for the klystron; 6- magnets power supplies and other controls; 7-shielded ERL vault with removable beams; 8- 2 MeV 704 MHz SRF photo-injector; 9- 15-20 MeV 704MHz 5–cell SRF linac; 10 –return loop; 11- beam dump; 12 – part of the 1.8K cryogenic system.

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The intensive R&D program geared towards the construction of the prototype ERL is under way: from development of high efficiency photo-cathodes [3] to the development of new merging system compatible with emittance compensation [4].

R&D ERL will serve as a test-bed for multiple future RHIC projects listed in Table 1:

- ERL-based electron cooling (conventional or coherent).
- 5-to-30 GeV multi-pass ERL for electron-ion collider eRHIC.

The R&D ERL will test many generic issues relevant with ultra high current continuously operation ERLs:

- SRF photo-injector (704 MHz SRF Gun, photocathode, laser) capable of 500 mA.
- Preservation of low emittance for high-charge, bunches in ERL merger;
- High current 5-cell SRF linac with efficient HOM absorbers.
- Stability criteria for Amp-class CW beam.

Table 1: Required parameters of future BNL projects based on ERL technology in comparison with under commissioning BNL R&D ERL designed parameters.

	R&D ERL design		**BNL ERL based projects**			
	High Current	High charge	PoP CeC Test		RHIC Pre-cooling @ 40GeV	eRHIC 5/30 GeV
Charge per bunch, nC	**0.7**	**5**	**5**	**5**	**14 (9x1.56)**	**5**
Energy maximum/injection, MeV	20/2.5	20/3.0	21/3	21/3	21/3	5000/100 30000/600
R.m.s. Normalized emittances ex/ey, mm*mrad	1.4/1.4	4.8/5.3	5	5	3	77
R.m.s. Energy spread, dE/E	$3.5x10^{-3}$	$1x10^{-2}$	$1.5x\ 10^{-3}$	$1.5x\ 10^{-3}$	$8\ 10^{-4}$	$1x10^{-3}$
R.m.s. Bunch length, ps	18	31	30	30	30	30
Bunch rep-rate, MHz	700	9.383	0.078	9.383	9.383	14.1
Gun/dumped avrg. current, mA	500	50	0.4	50	130	50
Linac average current, mA	**1000**	**100**	**0.4**	**0.4/50**	**130**	**600**
Injected/ejected beam power, MW	1.0	0.150	0.0012	0.15	0.390	0.5
Numbers of passes	1	1	1	1	1	6

GENERAL LAYOUT AND MODES OF ERL OPERATION

Our present ERL design (shown in Fig. 1.) has one turn: electrons are generated in the superconducting half-cell gun and injected into the main superconductive linac. Linac accelerates electrons to 15-20 MeV, which then traverse a one turn re-circulating loop with achromatic flexible optics [5].

Two operating modes (Tab.1) will be investigated, namely the high current mode and the high charge mode. In the high current (0.5 A) mode ERL will operate electron bunches with lower emittance 0.7 nC bunches with 703 MHz rep-rate. In this case the full energy of electrons at gun exit is limited to 2.5 MeV by the available RF of 1 MW. In a high charge mode, ERL will have electron beam with 5nC per bunch and 10MHz repetition rate, i.e. it will have 50 mA average current. In this mode, the electrons energy at the gun exit could be pushed higher. The limit of 3.0-3.5 MeV most likely will be determined by the maximum field attainable in the super-conducting gun.

FIRST STAGE - G5 TEST

Gun-to-5-cell cavity (G5) setup (Fig 2) can be considered as the first stage of the final BNL ERL beam commissioning. The goal of the G5 setup is to test critical ERL components with the beam and characterize the beam produced by the gun. Also, this test will be used to assess effectiveness of the zigzag merger, which will be installed later in the ERL setup. The major components under the test will include the SRF gun, the five-cell SRF cavity, vacuum components, parts of the control and diagnostic systems. The expected parameters for G5 test are summarized in table 2.

Table 2. Main parameters of electron beam for G5 test

Charge per Bunch:	0.005-5 nC
Gun Energy:	2.5 -3 MeV
Maximum Energy:	20 MeV
Energy spread on crest	3% ,off crest 15 %
Max. Average current:	500 nA
Max. Rep Rate:	100 Hz
Average Power:	< 10 W

During the G5 test we will have two modes of measurements:

1) in straight ahead mode: the quadrupole scan and flag will be used to measure projected emittances transverse halo and;
2) turning on bending magnet mode gives the nice opportunity to measure longitudinal parameters of the electron bunch:: bunch length, longitudinal tails. Slice emittance will be measured using off crest RF operation and slits.

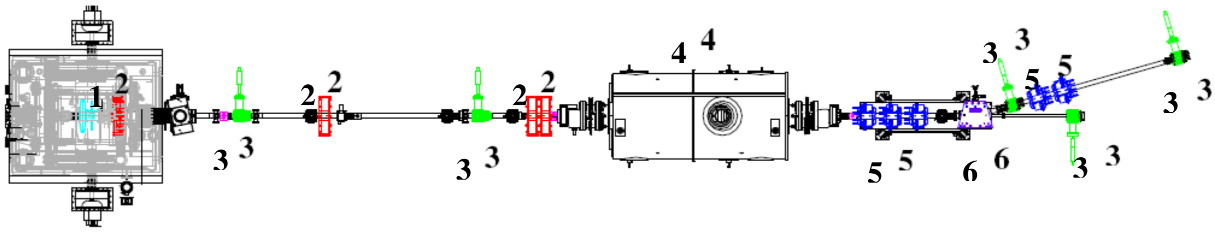

Figure 2: Detailed drawing of G5-test: 1 - 703MHz SRF gun; 2 – solenoids; 3 - beam profile monitors; 4- 5cell SRF cavity; 5-quadrupoles; 6-dipole magnet. 2.5 MeV electron beam from SRF gun propagates through a straight section with beam diagnostics: BPMs, pepper-pot, YaG/OTR screens. Then beam is accelerated in 5-cell cavity to 20 MeV.

All flags will be driven by multi-position pneumatic actuators, and will have both YAG and OTR capability at each location (Fig. 3).

Figure 3. Beam profile monitor plunging assembly. With RF shielding cage attached. Designed and built by RadiaBeam technology.

Most of the beam instrumentations and other equipment will be reused latter for full scale ERL commissioning and operation.

STATUS AND PLANS

Most of the ERL subsystems are designed, built and many of them installed and tested. The infrastructure had been installed in the Bldg. 912 of the CAD complex: 5 cell cavity [6], 1 MW CW klystron with power supply, 50 kW transmitter, cryogenic plant with all necessary infrastructure, machine protection system [], photo injector drive laser, photocathode deposition system with transport cart, stands for G5 test. Some components were preinstalled then removed magnets and stands for ERL loop. Movable arc is pre-surveyed and is ready to be installed. SRF gun has passed vertical test. The cavity without cathode performed very well. The multipactoring and available power limitation were not allowed to increase field in the gun during vertical test. The conditioning test of the gun is planned for this summer [8].

The first stage of ERL commissioning G5 test will be start this fall. Then the injection merger will be installed in order to test the concept of emittance preservation in a beam merger. Then the recirculation loop will be completed to demonstrate energy recovery with high charge per bunch and high beam current.

We have designed and start commissioning a small (about 20 meters in circumference) R&D ERL to test the key issues of amp-class CW electron accelerator with high brightness beams, required for future nuclear physics experiments eRHIC (the foot print of high power ERLs are shown on Fig. 5). Extensive R&D program on many novel components to be used in the ERL is under way. The prototype ERL will demonstrate the main parameters of the electron beam required for electron cooling and for electron ion colliers.

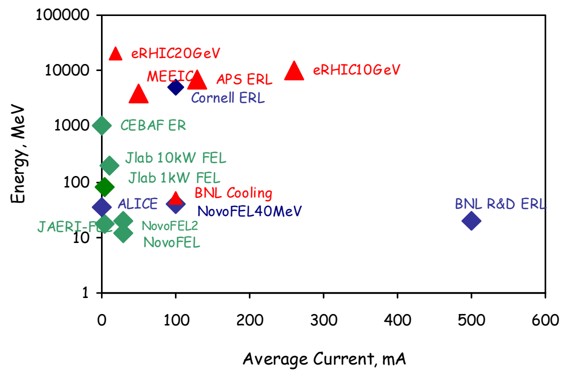

Figure 5: The High Power ERL landscape. Green are already demonstrated/operational, Red under design, Blue under commissioning.

This facility will serve as the test-bet for new range of beam parameters whose application will extend well beyond the goals set forward by Collider Accelerator Department at BNL.

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