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) [1] for testing concepts for high-energy electron cooling and electron-ion colliders. One of the goals is to demonstrate an electron beam with high charge per bunch (~ 5 nC) and extremely low normalized emittance (~ 5 mm-mrad) at an energy of 20 MeV. Flexible lattice of ERL loop provides a test-bed for testing issues of transverse and longitudinal instabilities and diagnostics of intense CW e-beam. The superconducting 703 MHz RF photoinjector is considered as an electron source for such a facility. At first we develop the straight pass (gun -- 5 cell cavity -- beam stop) test for the SRF Gun performance studies. Then the novel injection line concept of emittance preservation at the lower energy will be tested at this ERL. 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.

The ERL R&D program is started by the Collider Accelerator Department (C-AD) at BNL as an important stepping-stone for 10-fold increase of the luminosity of the Relativistic Heavy Ion Collider (RHIC). Furthermore, the ERL R&D program extends toward a possibility of using 10-20 GeV ERL for future electron-hadron/heavy ion collider, eRHIC [2].

Future RHIC upgrades define the goals for the R&D ERL development to test: 1) Test the key components of the High Current ERL based solely on SRF technology; 2) 703.75 MHz **SRF gun** test with 500 mA current; 3) 5-cell **SRF linac** test with HOM absorbers; 4) Single turn - 500 mA test the beam current stability criteria for CW operation; 5) Test the attainable ranges of electron beam parameters in SRF ERL; 6) Demonstrate beam quality close to that required for RHIC electron cooling and scalability to eRHIC.

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GENERAL LAYOUT OF R&D ERL

The R&D 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 up to 15-20 MeV, when electron bunch pass through a one turn re-circulating loop with achromatic flexible optics [3].

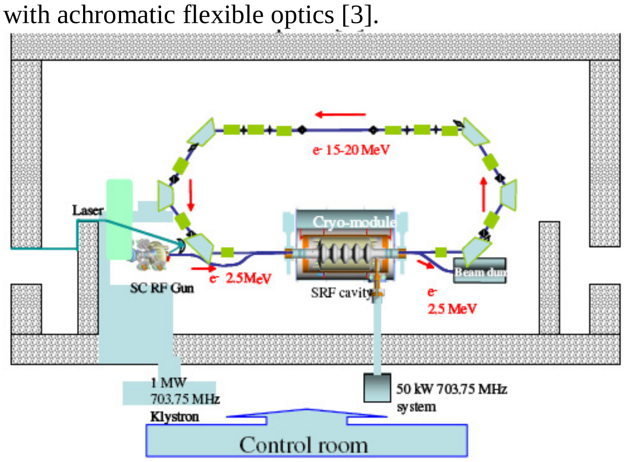

Figure1: Layout of the R&D energy recovery linac in the shielded vault.

The photocathode is located in a high electric field for immediate acceleration of the electrons to as high energy as possible, reducing emittance degradation due to strong space charge force. Furthermore, liner part of space charge effects is compensated by applying a suitable external solenoid magnetic field.

In nominal recovery operation regime the path-length of the loop provides for 180 degrees change of the RF phase, causing electron deceleration (hence energy recovery) down to injection energy. The decelerated beam separates from the higher energy beam and goes to the beam-dump.

ERL INJECTOR

The electron injector is a central part of any ERL that has to deliver high brightness electron beam. The BNL R&D ERL injector (see Fig. 2) consist of ½ cell superconducting RF gun with photocathode inside [4], solenoid, four dipoles and two solenoids turned on in opposite direction. The 4th dipole mergers the high and low energy beams. One of the novel systems we plan to use for the R&D ERL is a merging system providing achromatic condition for space charge dominated beam and compatible with the emittance compensation scheme. Focusing of the bending magnets in the merging section has significant effect on the low energy electrons. Different focusing in vertical and horizontal planes (astigmatism) makes impossible simultaneous emittance compensation. Hence, the use of combined function magnets with equal focusing strength in x- and y-direction is necessary.

Table 1: Electron Beam Parameters of the R&D ERL

Mode	**High current**	**High charge**
Charge per bunch, nC	1.4	5
Injection energy, MeV	2.5	3
Maximum beam energy, MeV	20	20
Average e-beam current, mA	500	50
Bunch rep. rate, MHz	350	9.38
Normilized emittance, mm*mrad	2.3/2.3	4.8/5.3
Rms energy spread, %	0.5	1
Rms bunch length, ps	20	30

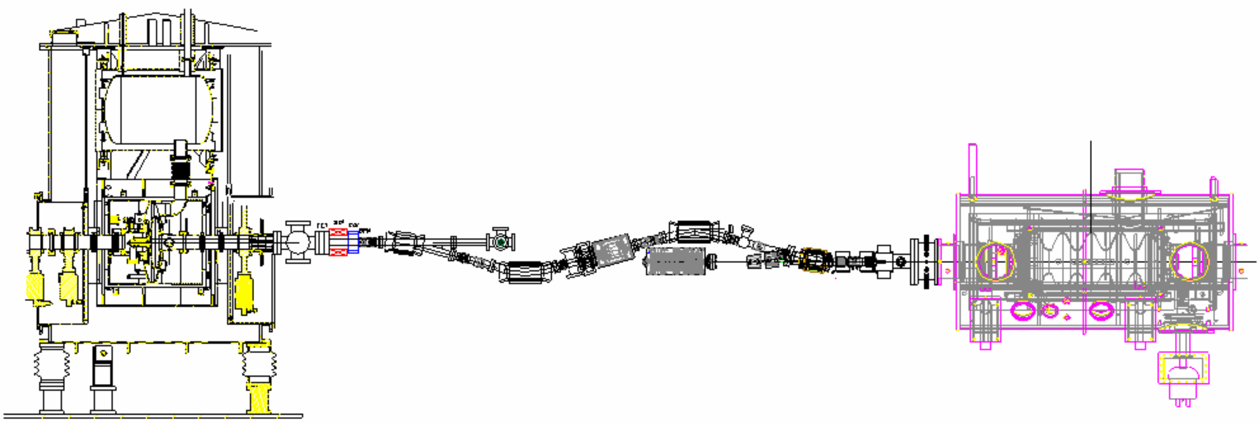

Figure 2: Detailed drawing of SRF Injector for the BNL R&D ERL.

Beam dynamics simulation shows that for Z-merger both vertical and horizontal emittances at the end of the linac can be the same [5].

The main expected electron beam parameters for the BNL R&D ERL obtained by PARMELA [6] simulations are listed in Table 1.

Due to the bends in vertical direction the effect of vertical emittance growth is clear. But at the exit of Z-merger both: vertical and horizontal emittances become almost equal. In case of 5 nC per bunch this equality is broken, the next order nonlinearity start playing a role.

5 CELL SRF LINAC

The heart of the ERL facility is 5-cell SRF linac, which is designed for operating with ampere-class CW beam current [7]. The cavity was designed as a "single-mode" cavity, in which all Higher Order Modes (HOMs) propagate to HOM ferrite absorbers through the large beam pipe. Measurements of the damped Q and R/Q of the HOMs and simulations show that in nominal operation regime the cavity is stable to over 20 amperes in a one pass ERL and over 2 amperes for two passes ERL.

The 5-cell SRF linac successfully went through vertical test at Jlab and the 20 MeV/m accelerating voltage was demonstrated [8]. We are finishing of the cryostat assembly (see Fig .3) and the cavity will go through a horizontal (a normal mode of an operation) cold-emission test (CET) in the ERL cave in November 2008.

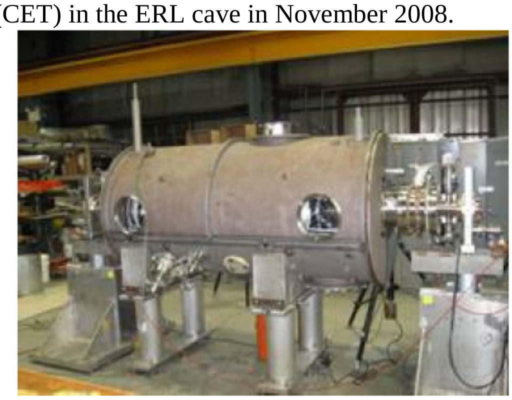

Figure 3: 5-cell cavity in the cryomodule.

GUN 5-CELL CAVITY TEST

We will start ERL commissioning from gun through 5-cell cavity (G5) beam test in 2009. The layout of G5 test is shown in Fig. 4.

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.

All flags will be driven by multi-position pneumatic actuators, and will have both YAG and OTR capability at each location. Images will be viewed off the ERL plane via mirrors.

The expected parameters for G5 test are summarized in Table 2.

Table 2. Main Parameters of Electron Beam for G5 Test

Charge per Bunch:	0.05-5 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

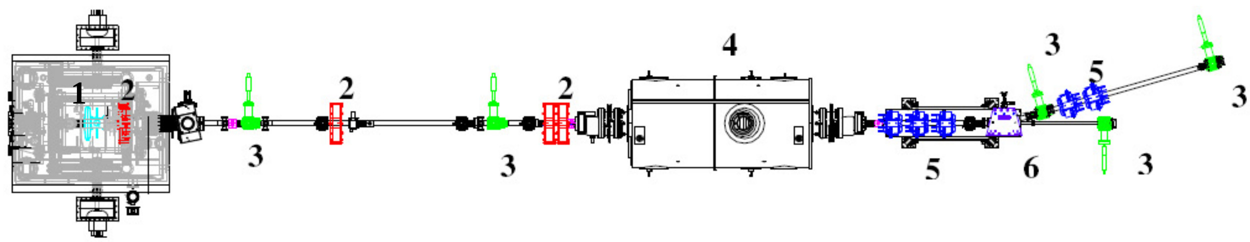

Figure 4: Detailed drawing of G5-test: 1 - 703MHz SRF gun; 2 – solenoids; 3 - beam profile monitors; 4- 5cell SRF cavity; 5-quadrupoles; 6-dipole magnet. 2.5 MeV electron beam from SRF gun propagates through a straight section with beam diagnostics: BPMs, pepper-pot, YaG/OTR screens. Then beam is accelerated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

STATUS AND PLANS

Many of the ERL subsystem and most of its infrastructure had been installed in the Bldg. 912 of the CAD complex:

- 5-cell Cavity is being processed and tested at JLAB, cold emission test 5-cell cavity in cryostat at BNL in November 2008
- 1 MW Gun klystron and 50 kW 5-cell cavity transmitter are installed, tested with dummy load at 0.6 MW level
- Recirculation loop magnets and vacuum system components are ready for installation
- Gun drive laser is been procured, will arrive in October 2008
- RF control will be based on the new digital RHIC LLRF. The LLRF system is currently under development.
- Machine protection system is being designed (BLMs, DCCTs)
- Gun is under construction at AES

BNL starts commissioning of the R&D ERL in 2009:

1) the straight pass (G5 test) or the beam quality studies.
2) test concept of emittance preservation in a beam merger in the same configuration as above
3) complete recirculation loop, demonstrate energy recovery with high charge per bunch and high beam current
4) study beam and stability issues relevant for high current ERLs

The availability of high current electron beam with low emittance (see Table 1) opens new perspective of using BNL R&D ERL as an electron beam provider for free electron laser [9]

After the testing main components of ERL in building 912 we are planning to use 20 MeV BNL R&D ERL to do a CeC proof-of-principle experiment to cool Au ions in RHIC at ~ 40 GeV/n [10]. As an example, the layout of CeC proof-of-principle test installed at RHIC IR2 is shown in Fig. 5 PoP CeC experiment using this ERL at RHIC could be possible in 2012

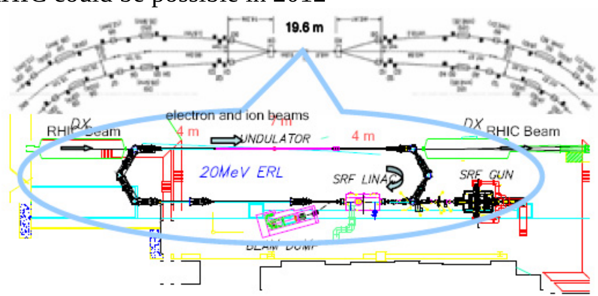

Figure 5: Coherent electron cooling proof-of-principle layout at RHIC IR2.

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