

HIGH CURRENT ENERGY RECOVERY LINAC AT BNL*

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Abstract

We present the design and parameters of an energy recovery linac (ERL) facility, which is under construction in the Collider-Accelerator Department at BNL. This R&D facility has the goal of demonstrating CW operation of an ERL with an average beam current in the range of 0.1 - 1 ampere and with very high efficiency of energy recovery. The possibility of a future upgrade to a two-pass ERL is also being considered. The heart of the facility is a 5-cell 703.75 MHz super-conducting RF linac with strong Higher Order Mode (HOM) damping. The flexible lattice of the ERL provides a test-bed for exploring issues of transverse and longitudinal instabilities and diagnostics of intense CW electron beams. This ERL is also

perfectly suited for a far-IR FEL. We present the status and plans for construction and commissioning of this facility.

ERL R&D PROGRAM AT BNL

The ERL R&D program is pursued by the Collider Accelerator Department at BNL as an important stepping-stone for a 10-fold increase of the luminosity of the Relativistic Heavy Ion Collider (RHIC) [1] using relativistic electron cooling [2] of gold ion beams with energy of 100 GeV per nucleon. Furthermore, the ERL R&D program extends toward the possibility of using 10-20 GeV ERL for a future electron-hadron/heavy ion collider, eRHIC [3].

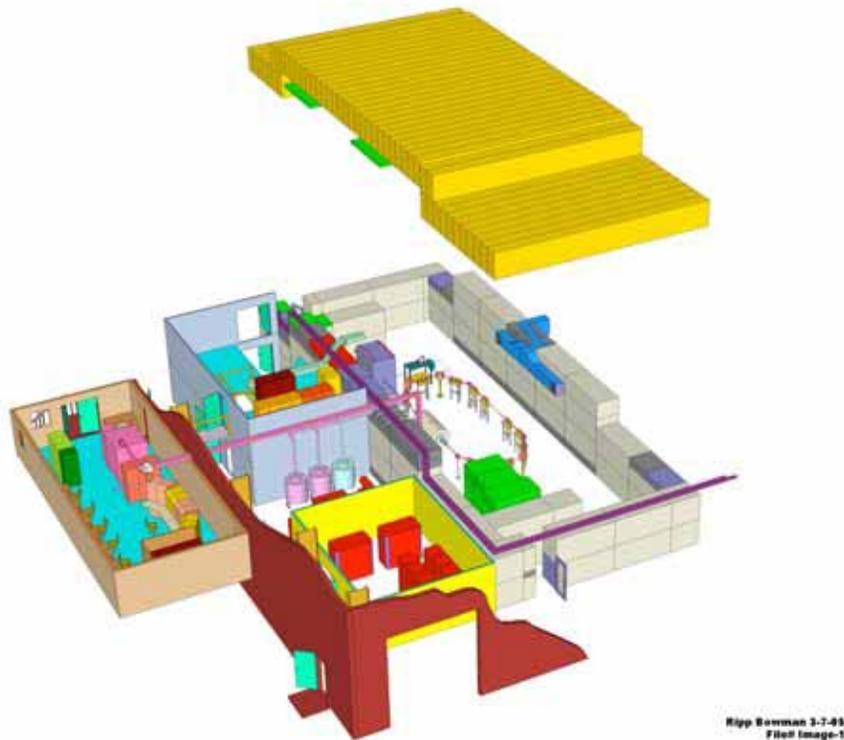


Fig.1 The layout of the R&D ERL facility in the bay of Bldg. 912 at BNL. The bay is equipped with an overhead crane. The facility has a control room, two service rooms and a shielded ERL cave. The control room is located outside of the bay in a separate building. The single story house is used for a 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

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The 10-fold increase of luminosity in RHIC II will extend the studies of quark-gluon plasma and QCD vacuum beyond the discovery phase towards their full characterization [1]. The ERL-based eRHIC with luminosity of $10^{34} \text{ cm}^{-2}\text{sec}^{-1}$ per nucleon will extend the capability of RHIC even further using polarized electrons to probe color glass condensate and spin structure of nuclear, to mention a few. These projects are the driving force behind the development of ampere-class ERL technology [4], which will find many applications including light sources and FELs. These programs also define the goals for the R&D ERL development:

- Test the key components of the RHIC II electron cooler
- Test the key components of the High Current ERL based solely on SRF technology
 - 703.75 MHz SRF gun test with 500 mA
 - High current 5-cell SRF linac test with HOM absorbers (one turn - 500 mA, two turns - 1 A)
 - Test the beam current stability criteria for CW beam currents $\sim 1 \text{ A}$
- Test the key components and scalability for future linac-ring collider eRHIC with
 - 10-25 GeV SRF ERL for eRHIC
 - SRF ERL based an FEL-driver for high current polarized electron gun
 - Test the attainable ranges of electron beam parameters in SRF ERL

The plans call for construction and commissioning of the prototype ERL within 3 years. The ERL will be located in one of the spacious bays in Bldg. 912 of the RHIC/AGS complex (see Fig. 1 and ref [5]).

The intensive R&D program geared towards the construction of the prototype ERL is under way: from development of high efficiency photo-cathodes [6] to

the development of new merging system compatible with emittance compensation [7].

Advanced Energy Systems, with the participation of BNL, have started the design and construction of the SRF gun [8]. The 5-cell SRF linac is under construction at Advanced Energy Systems and is planned to be installed and tested in Bldg. 912 this year. The 703.75 MHz, 1 MW CW RF system for the SRF gun is under procurement. The 50 KW 703.75 MHz RF transmitter for the linac has been installed at the site and is undergoing commissioning.

The lattice of the ERL is designed to fit with the most recent design of SRF injector [9]. The main feature of the lattice is that it provides a wide range of flexibility in transport matrix parameters to study both longitudinal and transverse beam break-up instability (BBU), while remaining achromatic.

LAYOUT AND MAIN COMPONENTS OF THE ERL

The baseline design (shown in Fig. 2) has single pass energy recovery mode: electrons are generated in the superconducting half-cell gun to about 2.5 MeV and injected through the Z-bend merging system with emittance compensation [7] into the main linac. The linac accelerates electrons to 15-20 MeV and these then pass through a one turn re-circulating loop with achromatic flexible optics. The path-length of the loop provides a 180 degrees change of the RF phase, causing the electron beam to decelerate (hence energy recovery) down to 2.5 MeV. The decelerated beam separates from the higher energy beam and goes to the beam-dump. The expected parameters of this system are listed in Table I.

A description of the SRF gun and its photocathode system can be found in [8]. The maximum current from this gun will be limited to about 0.5 A determined by the available RF power of 1 MW 703.75 MHz CW klystron.

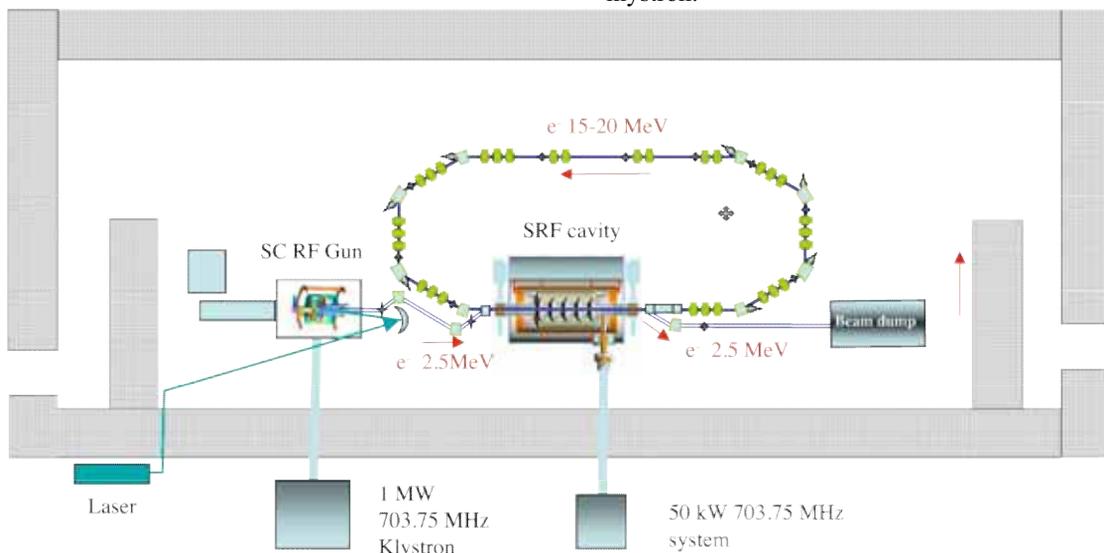


Fig. 2 Layout of the R&D linac in the shielded vault

A novel systems using Z-bend merging system providing achromatic conditions for the space charge dominated beam, and compatible with the emittance compensation scheme [7], will be used for the R&D ERL.

Table I. Parameters of the R&D ERL in Bldg. 912

	High charge	High current
Injection energy, MeV	2.5	2.5
Maximum beam energy, MeV	20	20
Average beam current, A, up to	0.2	0.5
Bunch rep-rate, MHz	9.4	703.75
Charge per bunch, nC	~20	1.3
Normalized emittance, mm*mrad	~30	~1-3
Efficiency of current recovery, >	99.95%	99.95%

The Z-system provides achromatic conditions for the electrons whose energy is changing while they propagate through the merging system. In contrast to the traditional chicane, where horizontal emittance suffers a significant growth as result of the bending trajectory, the emittances in the Z-system are equal to each other and are very close to the attainable for the straight pass [10].

The heart of the ERL facility is 5-cell SRF linac, which is designed for operating with ampere-class CW e-beams [4,5]. The main features of this design are the very large apertures of the structure, which effectively couples all HOMs to two ferrite absorbers, located on both sides of the cryo-module. This design provides for very low quality factors for HOMs resulting in very high ERL stability. Threshold current of the transverse beam break-up instability (TBBU) for the ERL with one 5-cell linac is measured in amperes [11]. We plan to intentionally tune the lattice of the ERL to a special mode for testing the TBBU predictions of our SRF linac with current limited only to few hundreds of milliamps.

The lattice of the ERL loop controls the parameters of a symplectic transport matrix [5], which affect the stability and operation conditions of the ERL. The lattice of the loop is intentionally chosen to be very flexible for the R&D ERL to be a test-bed of new ampere-range ERL technology. The adjustable part of the lattice has two arcs and a straight section. Each arc is an achromat with adjustable longitudinal dispersion. Quadrupoles in the dispersion-free straight section provides for matching of the β -function and for choosing the desirable phase advances independently in horizontal and vertical planes [9]. The threshold of TBBU instability will depend on the values of matrix elements m_{12} and m_{34} . Hence, we plan to increase these elements to the level of a few hundred mA, which is required to observe, or reliably measure transverse instability threshold, and compare it with predictions based on the cavity model.

We consider the potential extension of this facility into a two turn configuration and installation of an IR

FEL, if funds are available. The shielded vault is designed for ERL with maximum energy of 54 MeV to accommodate these future up-grades. The loop of the ERL is designed to accommodate a large energy spread of electron beam in order to operate a 100-200 kW CW FEL [5].

CONCLUSIONS

We are designing, constructing, and commissioning a small (about 20+ meters in circumference) R&D ERL to test the key issues of an amp-class CW electron accelerator with high brightness beams, required for future nuclear physics experiments at RHIC-II and eRHIC. An extensive R&D program on many novel components to be used in the ERL is under way. This facility, planned to be commissioned in 2007-2008, will serve as the test-bed for new ranges of beam parameters whose application will extend well beyond the goals set forward by the Collider Accelerator Department at BNL.

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