SUPERCONDUCTING RF LINAC FOR eRHIC*

S. Belomestnykh[1,2#], I. Ben-Zvi[1,2], J. C. Brutus[1], H. Hahn[1], D. Kayran[1], V. Litvinenko[1,2], G. Mahler[1], G. McIntyre[1], V. Ptitsyn[1], R. Than[1], J. Tuozzolo[1], Wencan Xu[1], A. Zaltsman[1]
[1)] Brookhaven National Laboratory, Upton, NY 11973-5000, U.S.A.
[2)] Stony Brook University, Stony Brook, NY 11794, U.S.A.

Abstract

eRHIC will collide high-intensity hadron beams from RHIC with a 50-mA electron beam from a six-pass 30-GeV Energy Recovery Linac (ERL), which will utilize 704 MHz superconducting RF accelerating structures. This paper describes the eRHIC SRF linac requirements, layout and parameters, five-cell SRF cavity with a new HOM damping scheme, project status, and plans.

INTRODUCTION

The proposed electron-ion collider eRHIC will collide ions from one of the rings of the existing heavy-ion collider RHIC with electrons from a new accelerator to be installed in the RHIC tunnel [1, 2]. eRHIC will utilize several superconducting RF accelerators. Layout of the SRF systems in the RHIC tunnel, their description, and main parameters were presented elsewhere [3]. The main electron accelerator, the subject of this paper, is a six-pass ERL with two 2.45-GeV SRF linac sections. After six re-circulations, the electron beam energy will be as high as 30 GeV.

SRF LINAC

Each SRF linac section will be 200-meters long. Due to rapid increase of the synchrotron radiation power at high energies, the beam current will be lowered at energies above 20 GeV to keep the total power loss below 10 MW. Thus, the highest luminosity will be achieved at 20 GeV. Parameters of the SRF linac are listed in Table 1.

Installing a shorter linac first and then gradually adding more SRF cryounits will stage the energy of the machine. The initial energy of the main ERL will be 10 GeV with three or four re-circulations. Only one linac section will be installed at this stage of the project.

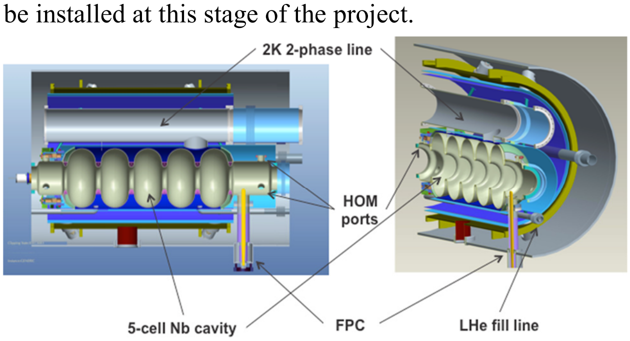

Figure 1: Preliminary layout of a cryounit for eRHIC.

*Work is supported by Brookhaven Science Associates, LLC under contract No. DE-AC02-98CH10886 with the US DOE.
#sbelomestnykh@bnl.gov

Table 1: Parameters of the Main ERL Linacs

Energy gain per linac section at 30 GeV	2.45 GeV
Beam current per pass (E ≤ 20 GeV)	50 mA
Bunch frequency	14.1 MHz
Bunch length	2 mm rms
RF frequency	703.8 MHz
Linac length	2×200 m
No. of cavities per linac	2×120
Filling factor	0.64
Cavity type	Elliptical, 5-cell
E_{acc} at 30 (20) GeV	19.2 (12.7) MV/m
Peak detuning due to microphonics	6 Hz
Q_{ext} FPC	5.9×10^7
RF power per cavity	10 kW
Total heat load at 1.9 K	5,700 W
Total heat load at 50 K	12,000 W

The SRF linac utilizes five-cell, 704-MHz cavities, described in the next section. Each cavity will be housed in an individual cryounit (Figure 1). A series of such cryounits will form one long cryomodule per section of the linac, with one-meter long transitions to room temperature at each end. The linac's accelerating gradient will reach 19.2 MV/m when operating at the highest energy. At 6 Hz peak detuning due to microphonic noise, the RF power is under 10 kW per cavity. The cavities will be powered from individual solid-state RF amplifiers.

FIVE-CELL CAVITY AND OTHER COMPONENTS

Cavity and HOM Damping

A superconducting cavity for high-current applications [4-6] is shown in Figure 2. The cavity, named BNL3, has an optimized geometry that supports strong damping of higher order modes (HOMs) while maintaining good properties of the fundamental mode. The damping is accomplished via six antenna-type couplers attached to the large diameter beam pipes [7]. The simulations show that this HOM damping scheme provides sufficient suppression of the parasitic impedance to satisfy eRHIC requirements. The cavity parameters are listed in Table 2.

ISBN 978-3-95450-122-9

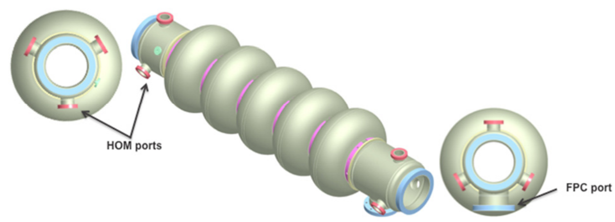

Figure 2: Five-cell 704-MHz SRF cavity for eRHIC.

Table 2: Parameters of the BNL3 Cavity

R/Q	506.3 Ohm
Geometry factor	283 Ohm
Cell-to-cell coupling factor	3.02%
Cavity loss factor (at $\sigma_z = 2$ mm)	3.96 V/pC
Cavity Q_0	4×10^{10}
E_{peak}/E_{acc}	2.46
B_{peak}/E_{acc}	4.27 mT/(MV/m)
Lorentz force detuning coefficient	0.45 Hz/(MV/m)^2
HOM power per cavity	7.3 kW
Operating temperature	1.9 K

Structural and thermal analysis, the cavity mechanical design, fabrication of a copper model and the first niobium cavity were done by AES, Inc. as part of collaboration with Stony Brook University and BNL. The full-scale copper model was designed and built with detachable end groups to provide more flexibility in studies of its HOM properties [6]. Because of a large cell-to-cell coupling, the initial field flatness was already very good at 90% right after manufacturing. It was improved to ±1.2% after tuning. The copper cavity is shown in Figure 3. A copper prototype of the HOM coupler is fabricated, and the HOM studies on this cavity are in progress [6].

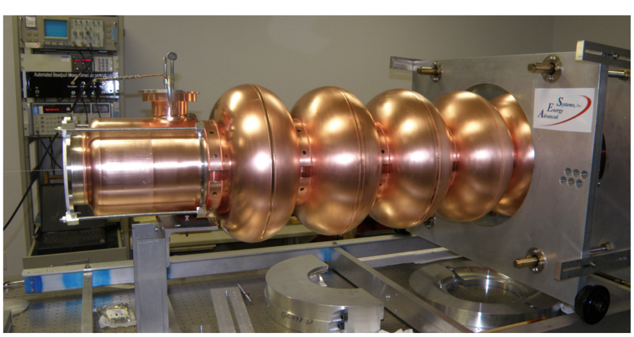

Figure 3: BNL3 cavity copper model undergoing frequency tuning at AES.

Fabrication of the first niobium cavity, BNL3-1, was completed recently at AES (Figure 4). It was made using 3-mm thick high-RRR material. All flanges are Conflat. RF measurements showed field flatness of ±3% and the resonant frequency within the specification so no cavity tuning was necessary after fabrication. The cavity is now being prepared for BCP, 600ºC vacuum bake and HPR. It will be tested at the BNL's vertical test facility in late 2012/early 2013.

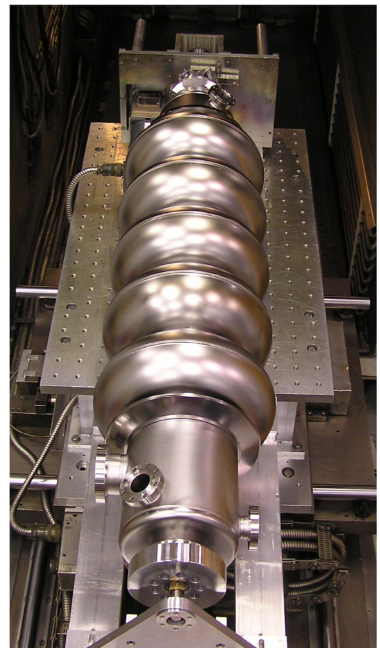

Figure 4: The first niobium BNL3 cavity (courtesy of AES).

Fundamental Power Coupler

As the RF power requirement for the eRHIC ERL cavities is relatively low (10 kW), the main emphasis of the fundamental power coupler (FPC) design is on minimizing its heat leak to 2 K system. Preliminary considerations [8] show that with a proper heat intercept the heat load at the cavity end is less than 0.4 W.

CRYOMODULE FOR COHERENT ELECTRON COOLING EXPERIMENT

The BNL3 cavity was chosen to provide an energy boost of 20 MeV to electrons in the Coherent electron Cooling Proof of Principle (CeC PoP) experiment in RHIC [9]. The new cavity (BNL3-2) and a single-cavity cryomodule are on order from Niowave, Inc. In addition to serving as the CeC PoP linac, it will provide valuable information for designing future eRHIC cryounits.

The BNL3-2 cavity will be fabricated from a 2.8-mm thick high-RRR niobium and will have a few design differences w.r.t. BNL3-1, while being interface-compatible with it. BNL3-2 will undergo processing similar to BNL3-1. The vertical testing at BNL is expected in mid-2013. Based on their vertical test performance, one cavity will be chosen for incorporating in the cryomodule.

SUMMARY

A 30-GeV ERL is proposed for the future electron-hadron collider eRHIC. The main ERL linac is based on five-cell, 704 MHz elliptical SRF structures. The cavities will have to accommodate high average beam currents and will have to be strongly HOM-damped to satisfy requirements imposed by BBU. The optimized cavity shape has been developed and the design of the HOM coupling scheme is in progress at BNL. The first cavity, BNL3-1, has been fabricated by AES and is being prepared for vertical testing. The second cavity is on order from Niowave. One of these prototype cavities will be used for the CeC PoP experiment.

REFERENCES

[1] V. Ptitsyn et al., "High Luminosity Electron-Hadron Collider eRHIC," IPAC'2011, p. 3726.

[2] V.Ptitsyn, "Overview of Assymmetric Electron Hadron Colliders," IPAC'2012, p. 1025.

[3] S. Belomestnykh et al., "Superconducting RF Systems for eRHIC," IPAC'2012, p. 2474.

[4] Wencan Xu, et al., "High current cavity design at BNL," *Nucl. Instr. and Meth. A* **622** (2010) 17-20.

[5] Wencan Xu, et al., "High Current SRF Cavity Design for SPL and eRHIC," PAC'2011, pp. 2589.

[6] Wencan Xu et al., "Progress on the High-Current 704 MHz Superconducting RF Cavity at BNL," IPAC'2012, p. 2486.

[7] Wencan Xu et al., "New HOM Coupler Design for High Current SRF Cavity," PAC'2011, p. 925.

[8] P. Jain et al., "Development of Fundamental Power Coupler for High Current Superconducting RF Cavity," IPAC'2012, p. 2483.

[9] I. Pinayev et al., "Status of Proof-of-Principle Experiment for Coherent Electron Cooling," IPAC'2012, p. 400.

ISBN 978-3-95450-122-9