DC PHOTOGUN GUN TEST FOR RHIC LOW ENERGY ELECTRON COOLER (LEReC)*

D. Kayran#, Z. Altinbas, D. Beavis, S. Bellavia, D. Bruno, M. Costanzo, A. V. Fedotov, D. Gassner, J. Halinski, K. Hamdi, J. Jamilkowski, J. Kewisch, C.-J. Liaw, G. Mahler, T. A. Miller, S. K. Nayak, T. Rao, S. Seletskiy, B. Sheehy, J. Tuozzolo, Z. Zhao
Brookhaven National Laboratory, Upton, NY 11973, U.S.A.

Abstract

Non-magnetized bunched electron cooling of low energy RHIC requires electron beam energy in range of 1.6-2.6 MeV, with average current up to 45 mA, very small energy spread, and low emittance [1]. A 400 kV DC gun equipped with photocathode and laser delivery system will serve as a source of high quality electron beam. Acceleration will be achieved by an SRF 704 MHz booster cavity and other RF components that are scheduled to be operational in early 2018. The DC gun testing in its installed location in RHIC will start in early 2017. During this stage we plan to test the critical equipment in close to operation conditions: laser beam delivery system, cathode QE lifetime, DC gun, beam instrumentation, high power beam dump system, and controls. In this paper we describe the gun test set up, major components, and parameters to be achieved and measured during the gun beam test.

INTRODUCTION

The LEReC uses a replica of the DC photocathode gun used in the Cornell University prototype injector, which has already been producing record high-brightness, high average current electron beams [2]. The gun has been built and is currently HV conditioning Cornell University. The gun will be operated with a multi-alkali NaK2Sb (or CsK2Sb) photocathode, which will be illuminated with green (532 nm) laser light with an oscillator frequency of 704 MHz. The 400 keV electron beam from the gun is transported via a 704 MHz SRF booster cavity and 2.1 GHz 3rd harmonic linearizer normal conductive cavity. Electron beam is accelerated to maximum kinetic energy of 2.6 MeV. In drift space electron bunch is stretched to required bunch length. Before entering the cooling section accumulated energy chirp is compensated by normal conductive 704 MHz cavity. Two dogleg-like mergers and mirror dipole are used to combine and to separate electron cooler electron beam with/from RHIC ion beams. The layout of LEReC is shown in Fig. 1. The optics of entire transport line has been designed and optimized to delivery electron bunches for different operation energies with quality satisfied electron cooling requirement (Table 1) [3].

Table 1: LEReC Electron Beam Requirements

Kinetic energy, MeV	1.6	2.0	2.6
Bunch Charge, pC	130	160	200
Bunches per train	30	27	24
Macro bunch charge, nC	3.9	4.3	4.8
Macro bunch rep. f, MHz	9.3	9.3	9.3
Total beam Current. mA	36	40	45
Normalized Emittance, μ	< 2.5	< 2.5	< 2.5
Energy spread, 10^{-4}	< 5	< 5	< 5

PURPOSE OF LEREC GUN TEST

The gun beam test (see Fig. 2) is the first stage of LEReC commissioning. Our aim is to test critical LEReC equipment in close to operation condition. This will demonstrate that the DC gun with photocathode meets its performance specifications and can work reliably.

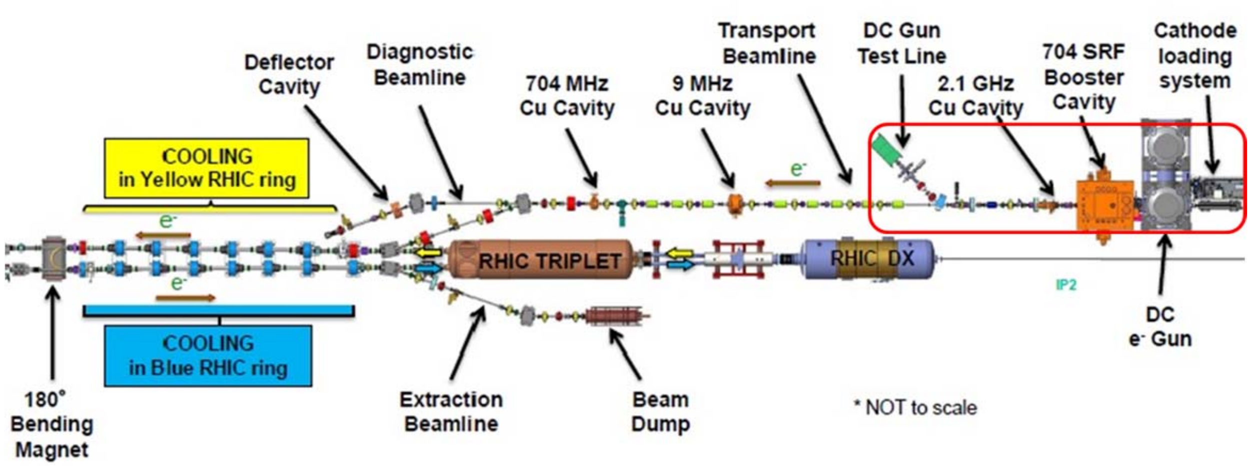

Figure 1: Layout of LEReC accelerator. Red contour box indicates DC gun test area.

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#dkayran@bnl.gov

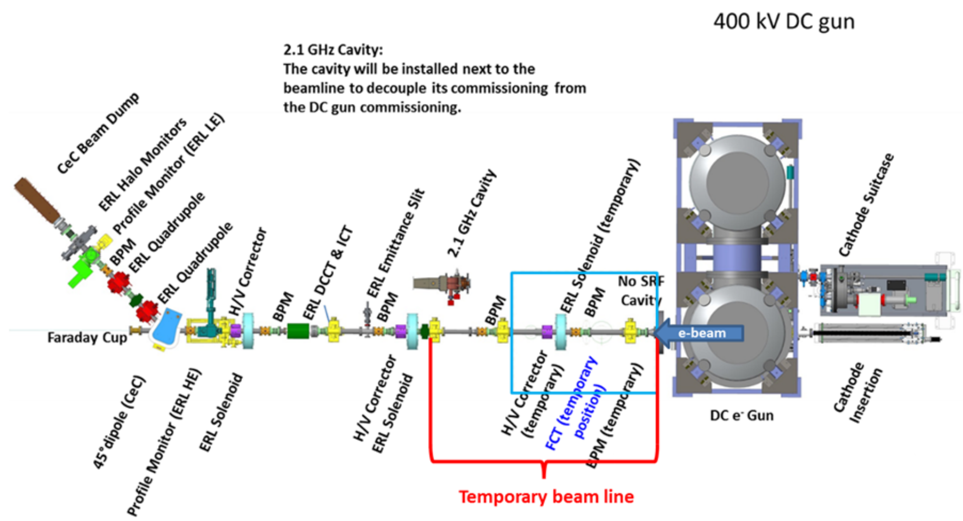

Figure 2: LEReC DC gun beam test layout. 2.1 GHz 3rd harmonic cavity (tested aside of beam line) and 704MHz SRF cavities (shown as a blue box contour) will be installed in replacement of temporary beam line after gun test is finished in fall of 2017.

Components to be tested during gun commissioning: a) laser beam delivery system (laser, laser shaping, laser transport, laser pulse stability); b) vacuum components; c) cathode manipulation system; d) DC gun characterization (stability, maximum operation voltage, electron beam quality); e) magnets (power supply); f) beam instrumentation; g) Control system (timing system, machine protection system, control of laser, gun power supply etc.); h) high average power beam extraction and dump system.

Gun test is designed to measure: a) beam energy and energy spread; b) emittance (ε) and Twiss parameters (α, β) using solenoid scan and/or slits; c) Longitudinal and transverse halo. During later runs with booster cavity installed we should be able to measure: bunch length and slice emittance. The Gun test main parameters are listed in Table 2.

Table 2: Gun Test Expected Parameters

Parameter	Value	Units
Kinetic Energy	0.4	MeV
Bunch charge	130	pC
Laser frequency	704	MHz
Laser pulse duration	80	psec
Macro-bunch charge	3.9	nC
Macro-bunch repetition rate	9.3	MHz
Normalized emittance	1-1.5	mm mrad
RMS bunch size	1-3	mm
Maximum average power	10	kW

GUN TEST LAYOUT

The gun to booster beam line includes two solenoids, H/V correctors, laser insertion and extraction ports, beam profile monitor (PM), and two beam position monitors (BPM) (see Fig. 3).

Temporary line (see Fig. 2) consists of: ERL type solenoid, H/V corrector, beam position monitors (BPMs), fast current transformer (FCT).

Transport line consist of: two ERL solenoids, two H/V correctors, three BPMs, integrated current transformer (ICT), direct current transformer (DCCT), multi-slits, and PM. Straight ahead line is terminated by Faraday cup (FC) at the end. This line could be used for current control and transverse emittance measurements (for LEReC beam instrumentation details see [4]).

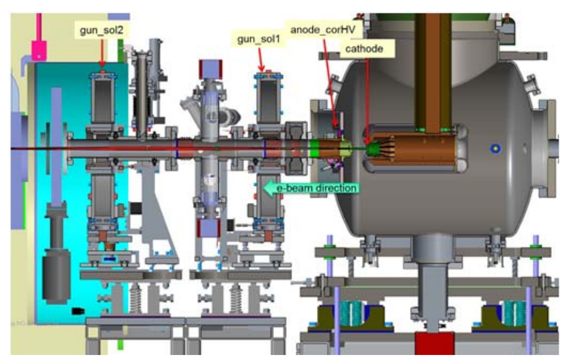

Figure 3: LEReC gun area side view.

Beam dump extraction line consists of CeC type 45-degrees dipole, two ERL quadrupoles with trims (one horizontal, one vertical correction), BPM, PM, 2D halo monitor, and fast current transformer (FCT). Inclined beam line is terminated by CeC type beam dump that also serves as a Faraday cup. The inclined line will be used for beam energy and energy spread measurements, transverse and longitudinal halo studies.

With later installed RF cavities this line could be used for bunch length measurements and RF cavities phase tuning.

BEAM DUMP

The beam dump is cooled from top and bottom by water circulation (Fig. 4). The sides are cooled only by copper thermo-conductivity. For optimum cooling, the electron beam will be spread more in the vertical direction. The beam profile monitor is used to match the electron beam with the aperture of the beam dump. At high beam power a BPM will provide an interlock if the beam trajectory is out of a predefined range of offsets (for LEReC machine protection system details see [5]). A second protection method uses four sets of slightly inserted halo monitors. These monitors measure very small current deposition on any of the four beam dump jaws in order to detect any beam profile changes.

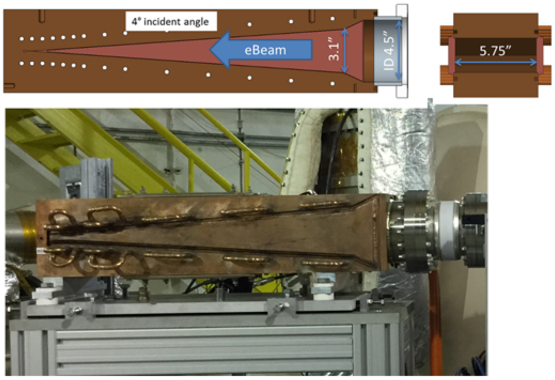

Figure 4: Beam dump geometry.

Optics of the inclined beam line is flexible enough to transport beam at all LEReC required energies to the beam dump (see Fig. 5).

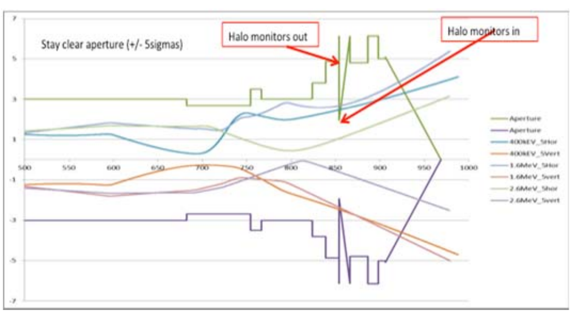

Figure 5: Stay clear aperture (5x rms beam envelop size) and vacuum pipe aperture in beam-dump line for 3 different energies.

Many beam line components are transferred from R&D ERL test facility [6] and CeC PoP experiment [7]: SRF cavity, solenoids, quadrupoles, magnets power supplies, beam profile monitors, beam position monitors, DCCTs, ICT, 45 degrees dipole, 10 kW beam dump. Rest of the beam line components have been designed and are currently being procured.

MAGNETIC SHIELDING

The energy of the electrons leaving the gun is ~400 keV. A residual field 0.5 Gauss (Earth's magnetic field) in 1 m will bend the beam to 20 mrad. The beam shift could be on the order of 1 cm. After 2 m of drift space, the beam would be lost on the minimum aperture of the vacuum chamber. On the bench test confirmed that 3 layers of 9 mils of μ-metal foil wrapped around the vacuum chamber sufficient to reduce field inside to 0.05 Gauss for external field up to 2 Gauss.

BEAM CURRENT RAMP UP

Space charge could play significant effects to beam dynamics. In order to increase average current preferable scenario is to keep charge per pulse constant while increasing numbers of macro-pulses.

Alternative could be increasing charge per bunch while keep pulse pattern untouched. As a results beam envelope will vary with space charge. For example on Fig. 6 we show RMS envelopes from gun to dump as a result of PARMELA [8] simulation with nominal space charge and significant low charge. We will explore both options of ramping up current during gun commissioning.

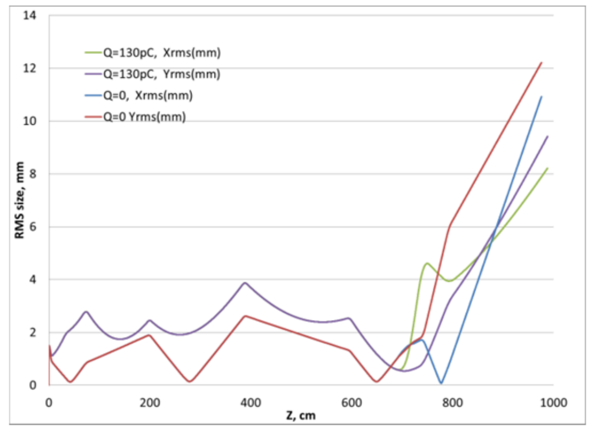

Figure 6: RMS beam envelope in the gun test beam line for nominal charge of 130 pC and very small charge of 0.13 pC.

SUMMARY

To reduce risk we will start commission the DC gun photoinjector for LEReC during RHIC Run 17.

Gun test is designed to provide initial studies of DC gun performance and test key concepts for LEReC commissioning: MPS operation, cathode delivery system, laser system, high average current capability etc.

The optics of extraction line is flexible enough to accommodate different energies required for later stages of LEReC operation.

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