BEAM OPTICS FOR THE RHIC LOW ENERGY ELECTRON COOLER (LEReC)*

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Abstract

A Low-energy RHIC Electron Cooler (LEReC) [1] system is presently under construction at Brookhaven National Laboratory. This device shall enable gold ion collisions at energies below the design injection energy with sufficient luminosity. Electron beam with energies between 1.6, 2.0 and 2.6 MeV are necessary. This machine will be the first to attempt electron cooling using bunched electron beam, using a 703 MHz SRF cavity for acceleration. Special consideration must be given to the effect of space charge forces on the transverse and longitudinal beam quality. We will present the current layout of the cooler and beam parameter simulations using the computer codes PARMELA [2].

INTRODUCTION

The nuclear physics program for the Relativistic Heavy Ion Collider (RHIC) for the 2019 and 2020 run periods concentrates on the search for the QCD phase transition critical point. Gold-gold collisions at energies between 2.9 and 4.8 GeV are required for this program, which is well below the design injection energy of RHIC of 10.5 GeV. At those energies intra-beam scattering is strong and a significant luminosity improvement in RHIC with the help of electron cooling is necessary.

Unlike all existing electron coolers the LEReC will use bunched electron beams for cooling. This introduces strong longitudinal space charge forces and the electron beam must not only be optimized for a low transverse emittance but also for a low energy spread in order to achieve efficient cooling.

Table 1: Electron Beam Parameters and Requirements

Energy [MeV]	1.6	2.0	2.6
Bunch Charge for Cooling [pC]	100	120	150
Accelerated bunch Charge [pC]	130	160	200
Bunches per train	30	27	24
Total beam Current [mA]	40	40	44
Normalized Emittance [μ]	< 2.5	< 2.5	< 2.5
Energy spread $\cdot 10^{-4}$	< 5	< 5	< 5

In the calculation of the beam quality we take advantage of the fact that electrons that are too hot (i.e. have a too high velocity in the co-moving frame) do not contribute to the cooling but do not harm either. For the calculation at 1.6 MeV 130 pC bunches are tracked, and 100 pC (electrons with the lowest energy deviation) are used for the evaluation of the beam parameters.

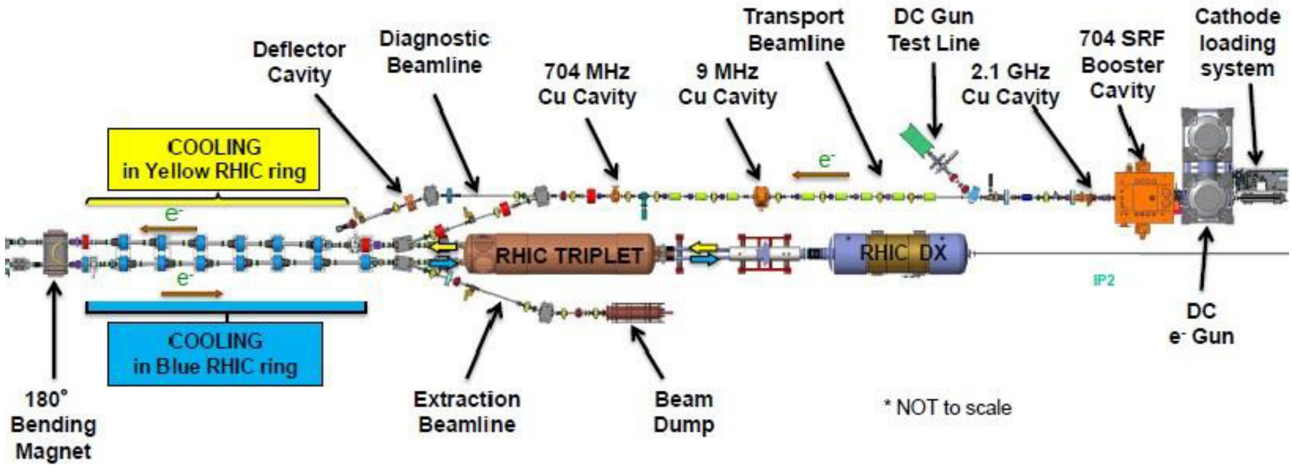

Figure 1: Layout of LEReC accelerator.

DESIGN OF THE LEREC

The layout of the LEReC is shown in Figure 1. The electron bunches will be created using a DC photocathode electron gun to be built for LEReC by Cornell University, which will operate at 400 kV. A similar gun at Cornell University has already delivered beams exceeding the required quality (300 pC, 50 mA, ε_n=1μ). The SRF gun used in the Brookhaven ERL will be transformed into a cavity (then called "SRF booster") and will provide an energy boost up to 2.25 MeV.

The SRF booster is too tall to be installed in the RHIC tunnel. It has to be placed in the 2 o'clock experimental hall. A transport beam line will bring the electrons to the "warm section" of RHIC.

The SRF booster will not only accelerate the electrons,

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*Work supported by the US Department of Energy under contract No. DE-SC0012704.
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but also introduce an energy chirp, which causes ballistic stretching of the bunch as it drifts through the transport beam line. A warm 700 MHz cavity removes the energy chirp before electron and ion beams are merged in the cooling section. A warm cavity operating at 2111 MHz (3rd harmonic, located next to the SRF booster) corrects the second order energy chirp.

At the end of the first cooling section the electron beam turns around in a single 180 degree magnet and is merged with the counter-rotating ion beam.

Both cooling sections include eight solenoids, spaced 3 meters apart. They are used to keep the beam size constant and minimize the angular spread.

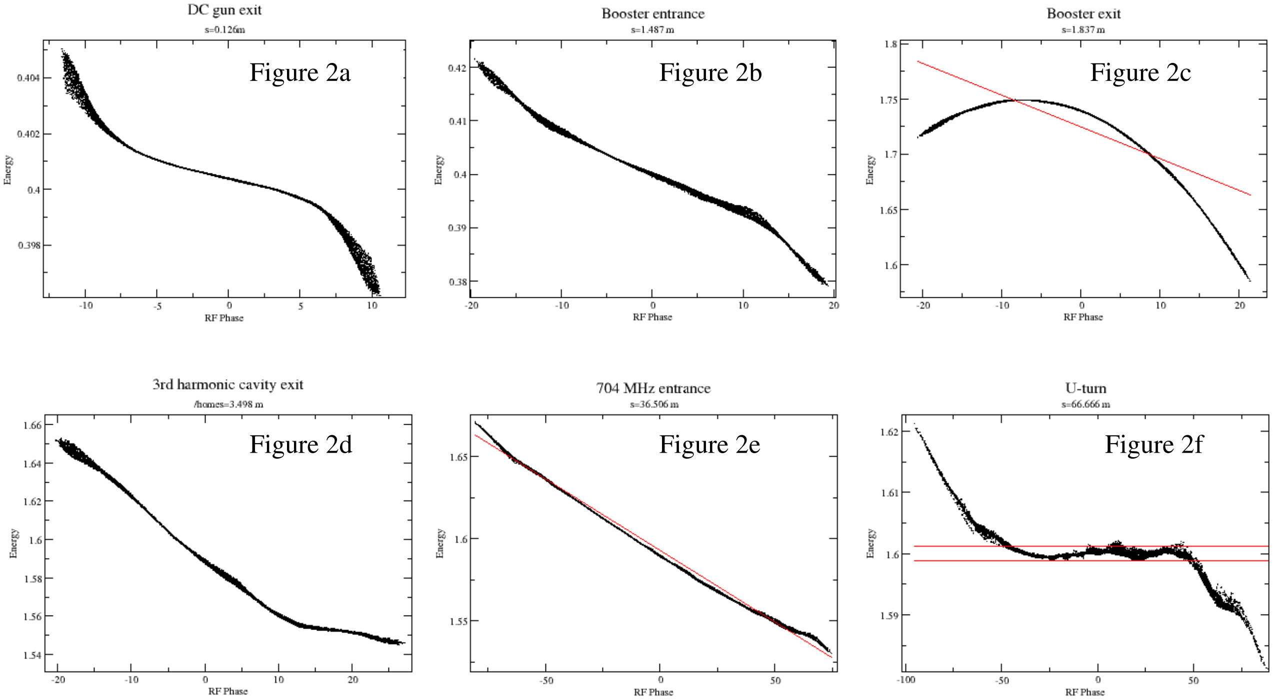

Figure 2: Development of bunches in longitudinal phase space.

LONGITUDINAL OPTICS

Figure 2 shows the development of bunches in longitudinal phase space. At the exit of the DC gun (Fig. 2a) the bunch has 400 kV with a significant energy spread, stemming from the fact that the space charge forces of the electrons in the head of the bunch reduce the accelerating voltage of the following electrons.

By the time the bunch reaches the entrance of the booster (Fig 2b) the energy spread has increased by a factor of five due to space charge and the bunch length has doubled. It is therefore essential to place the booster as close as possible to the gun, allowing only the absolute necessary instrumentation, laser mirrors and focusing solenoids between the two.

The SRF booster cavity accelerates the bunch near the top of the RF wave, and the cosine shape of the voltage gives the head and tail of the bunch less energy than the middle (Fig 2c). The bunch length at the cathode (±10 RF degrees, 80 ps) minimizes the bunch length in the booster to reduce this effect. A shorter bunch length at the cathode would increase the space charge force and therefore increase the bunch length in the booster. The booster introduces also an energy chirp (indicated by the red line in Fig 2c) to the bunch for ballistic stretching of the bunch in the transport section.

The remaining curvature of the bunch in phase space is then corrected by decelerating the beam in a 3rd harmonic cavity, so that the bunch is nearly linear in phase space (Fig 2d).

The transport section is about 30 meter long and the RMS bunch length increases to 4.5 cm (±75 RF degrees). With this length (Fig.2e) the longitudinal space charge is weak enough to go through the 2x20 m cooling sections without further correction of the energy spread. The bunch is still short enough so that the energy chirp can be removed with a warm 704 MHz cavity.

Fig. 2f shows the longitudinal phase space at the u-turn magnet. As mentioned above only 70% of the electrons contribute to the cooling process. Those are the electrons inside the red lines. It is unavoidable that the tails of bunches in an electron cooler with bunched beams have a larger energy deviation due to the longitudinal space charge.

The energy spread in the cooling sections is shown in Figure 3. The red curve includes the whole beam, black the 70%, blue is the requirement.

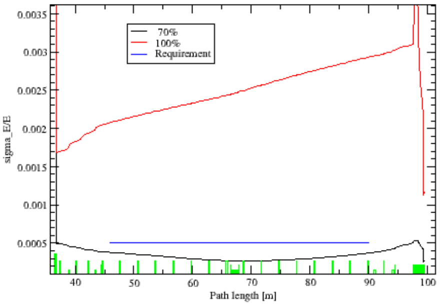

Figure 3: Energy spread in the cooling sections

TRANSVERSE OPTICS

Figure 4 shows the RMS beam envelope of the LEReC. In the cooling sections the envelope is kept constant, so that the angular spread (i.e. the transverse temperature) is minimized.

There are two solenoid magnets between the gun and the booster (Figure 5). The first is located directly after the gun and is used to curb the growth of the beam envelope, so that the laser mirrors are not hit. The second is located to focus the beam into the entrance of the booster, which optimizes the beam emittance. There are no solenoids between the booster and the 2100 MHz cavityto avoid emittance degradation by chromaticity.

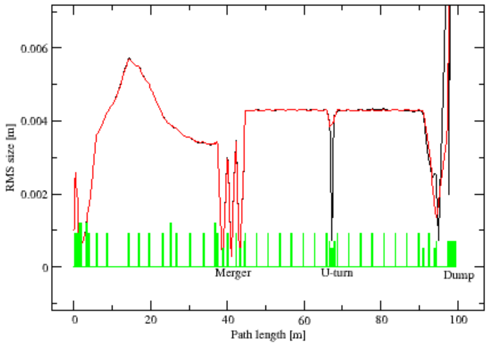

Figure 4: RMS beam envelope along entire electron beam transport through both cooling sections at 1.6 MeV.

The merging dog leg (Figure 6) is achromatic, using two solenoids to match the dispersion function. The solenoids have opposing polarity and introduce only local vertical dispersion.

Although the dipoles have a large bending radius they introduce significant focus. To avoid over-focusing the beam size is reduced in these dipoles by the up-stream solenoids. The dipoles are chevron magnets with equal focusing in both planes to keep the beams round.

The turn-around is not achromatic. It turns out that the degradation of the transverse emittance by the unmatched dispersion is smaller than the degradation through space charge forces when strong focusing is employed to match the dispersion function.

Figure 7 shows the normalized projected emittance, which fulfils the requirements. There is some degradation of the horizontal emittance (black) after the U-turn due to the dispersion.

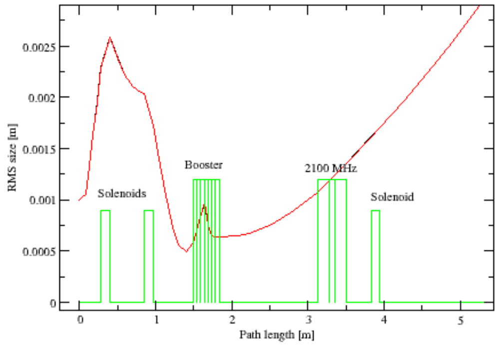

Figure 5: RMS beam envelope in the acceleration section.

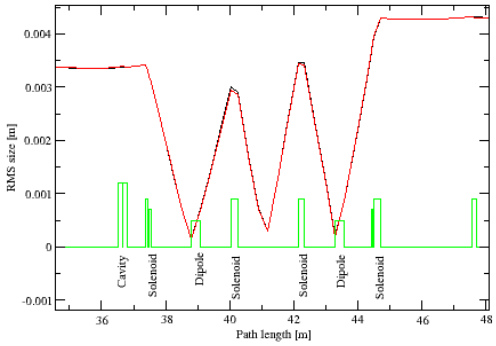

Figure 6: RMS beam envelope in the merging section.

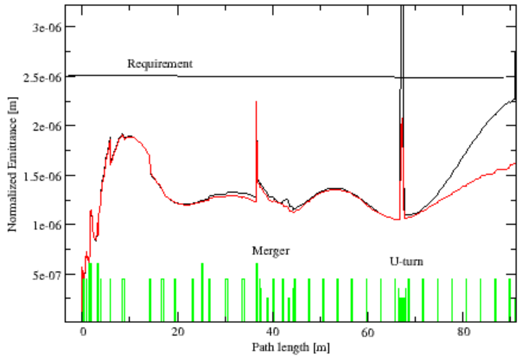

Figure 7: Projected beam emittance at 1.6 MeVusing 70% of the beam. The wave in the emittance is caused by the differences of focusing of the longitudinal slices of the bunch.

SUMMARY

The optics of the LEReC has been carefully optimized to fulfil not only the transverse but also the longitudinal beam quality requirements.

REFERENCES

[1] A. Fedotov et al., “Accelerator physics design requirements and challenges of RF based electron cooler Lerec”)”, these proceedings,WEA4CO05

[2] L.Young, J.Billen , PARMELA, LANL Codes.