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# HIGH-CURRENT DC GUN FOR LOW ENERGY RHIC COOLER PROJECT*

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*Abstract*

Electron cooling of ion beams employing rf-accelerated electron bunches was successfully used for the RHIC physics program in 2020 and 2021. Low energy RHIC electron Cooler (LEReC) uses a high-voltage photoemission electron gun with stringent requirements for beam current, beam quality, and stability. The electron gun has a photo-cathode with a high power fiber laser, and a novel cathode production, transport, and exchange system. It has been demonstrated that the high-voltage photoemission gun can continually produce a high-current electron beam with a beam quality suitable for electron cooling. We describe the operational experience with the LEReC gun in RHIC and discuss the important aspects needed to achieve the required beam current, beam quality, and stability. We also present recent gun tests in which stable operation at 50mA CW beam current was established.

## INTRODUCTION

The LEReC system [1–7] at Brookhaven National Laboratory utilizes several cutting-edge accelerator physics technologies. It comprises a high quantum efficiency photocathode production and delivery system, a high power laser system, a high-voltage, high-current DC photoelectron gun, and an RF system with several RF cavities.

### *Cathodes*

During RHIC operation with cooling, LEReC ran continuously without interrupting physics program. A cathode deposition [8] and exchange systems ensured a continuous supply of high performance photocathodes. To ensure this, two cathode deposition systems, three multicathode carriers, and a rapid cathode puck insertion system were built and successfully used in operations.

### *Laser*

Several recent advancements in the laser power and technology have further enhanced the performance of the LEReC providing high-brightness electron bunches, which are requried for the electron cooling appications. During the LEReC operation, the pointing stability of the electron beam was critical. A high power fiber laser with a center of mass (CoM) stability on the cathode of 10 µm rms was used.

### *DC Gun*

Electron bunches are produced by a high-voltage DC electron gun. The LEReC electron gun was built by Cornell University based on their existing high-voltage photoemission gun, with some small refinements.

### *Feedbacks*

LEReC incorporated multiple feedback systems providing reliable operation of the accelerator. The feedback systems include laser position feedback, laser intensity feedback, RF-laser timing feedback, energy feedback, and automatic cooling section orbit correction.

## HIGH-CURRENT DC GUN OPERATION

LEReC is a fully operational electron cooler that utilizes RF-accelerated bunched electron beams and non-magnetized electron beam technology. It has demonstrated stable operation 24/7, providing high-current electron acceleration and cooling of ion bunches consistently over many months during collider operations in 2020 and 2021.

The optimal electron beam current, aimed at maximizing luminosity while considering cooling and other effects such as ion beam lifetime, was determined to be 16-20 mA in 2020 (using 2 MeV electrons to cool Au ions at 4.6 GeV/n) and 10-20 mA in 2021 (using 1.6 MeV to cool Au ions at 3.85 GeV/n). To provide required CW electron beam current, the system utilized CsK2Sb photocathodes with an initial Quantum Efficiency of 8 – 9% and a cathode lifetime of 2-3 weeks, driven by vacuum inside the gun.

As shown in Fig. 1, LEReC DC gun provided 10-20 mA electron beam current in 2020 and 2021 for many months of operation. The LEReC contributed to enhancing the luminosity of RHIC operations at low energies of 3.85 and 4.6 GeV/n.

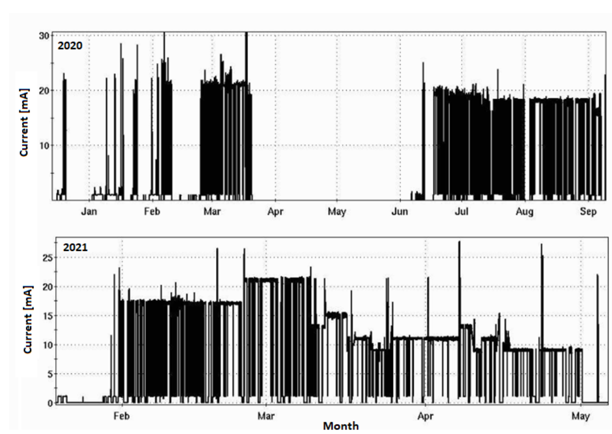


Figure 1: LEReC high-current operation overview in 2020 and 2021.

Physics stores at 4.6 GeV/nucleon with cooling (2 MeV) showed higher initial event rates and longer durations with

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cooling. Beta* squeeze became feasible after the transverse sizes of the ion beam were cooled. The gains in integrated luminosity from cooling were notable: approximately a factor of 2 in 2020 at 4.6 GeV/nucleon and between 30 – 50% in 2021 at 3.85 GeV/nucleon.

In addition to RHIC operations, LEReC gun has supplied electron beams for various studies, including cooling studies and high-current beam experiments required by the EIC project, in 2022.

To have a stable operation of the gun at high-current, several key measures were implemented:

- Application of a 3 kV anode bias to prevent ion back bombardment, which significantly increased stability. Without this bias, the DC gun would trip every 20-30 minutes.
- Utilization of an off-center, small area active cathode contributed to improved performance and stability.
- Implementation of laser feedback systems, including intensity feedback and RF-laser timing, enhanced stability and control of the electron beam.

First stable operation of the gun at 30 mA current was achieved in September 2018, see Fig. 2.

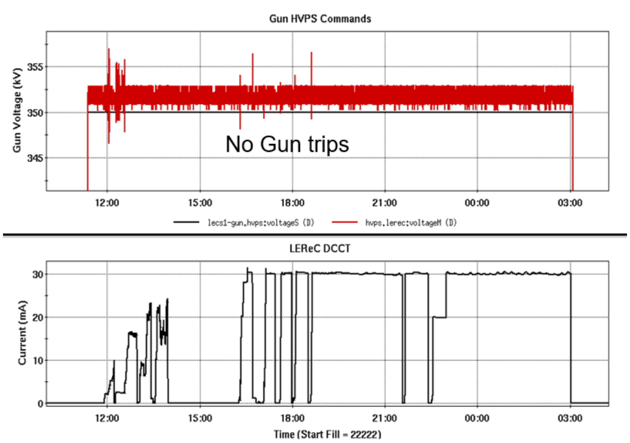


Figure 2: 30 mA CW electron beam current test in 2018.

## HIGH-CURRENT TEST

With up to 100 mA needed for the EIC pre-Cooler [9], dedicated high-current studies are planned using two approaches. The first involves directing the electron beam to a high power beam dump (140 kW), requiring dedicated RHIC time, as electron beam has to travel through common sections shared with hadron beams. Alternatively, the electron beam can be directed to an injection dump while operating in parallel with RHIC. However, the total electron beam power is now restricted by the capacity of the injection dump (25 kW).

Figure 3 shows the LEReC injection line with its main components.

During the high-current test in the injection line, the following parameters were configured:

1. **Laser Frequency**: Initially set at 9 MHz, it was adjusted to the full 704 MHz range. This adjustment aimed to reduce space charge effects, focusing primarily on the performance of the DC gun.

2. **Laser Micro-Bunch Length**: Initially set at 26 ps, with potential options of 40ps or 80ps in future tests.

3. **Laser Size**: The diameter of the laser beam spot on the cathode was reduced from 4mm to 3mm. This adjustment was aimed to improve laser propagation from the gun to the gun exit table.

4. **Gun HVPS Voltage**: Three voltage settings were tested: 375 kV, 350 kV, and 320 kV. These settings were chosen to mitigate the risk of inverter faults at 375 kV and over-current HVPS faults at 350 kV.

5. **Booster Cavity**: The voltage of the booster cavity was increased from 125 kV to 165 kV. For 50 mA, this adjustment ensured that the electron beam energy remained below 500 kV, which is the total voltage of gun voltage and booster cavity voltage, in consideration of the 25 kW injection dump limitation.

6. **Offset Activated Cathode Area**: Utilizing a 3 mm radius with a 4 mm offset for the activated cathode area.

7. **Anode Bias**: Maintained at 3000 V to ensure proper operation of the system.

8. **Bias BPM (Beam Position Monitors)** for BPM 5 and 6: set at ±200 V for ion cleaning.

Figure 4 shows stable operation at 50 mA CW electron beam current. The current was intentionally ramped down prior to the next polarization measurements in RHIC, which typically result in high losses at the location of the DC gun and may trip gun HVPS. The maximum current of 50 mA was limited by the injection dump power (25 kW).

## CONCLUSION

In summary, LEReC represents a reliable extension of electron cooling technology to high energies. LEReC has demonstrated its ability to deliver stable, high-current high-brightness electron beams for electron cooling applications.

## ACKNOWLEDGEMENTS

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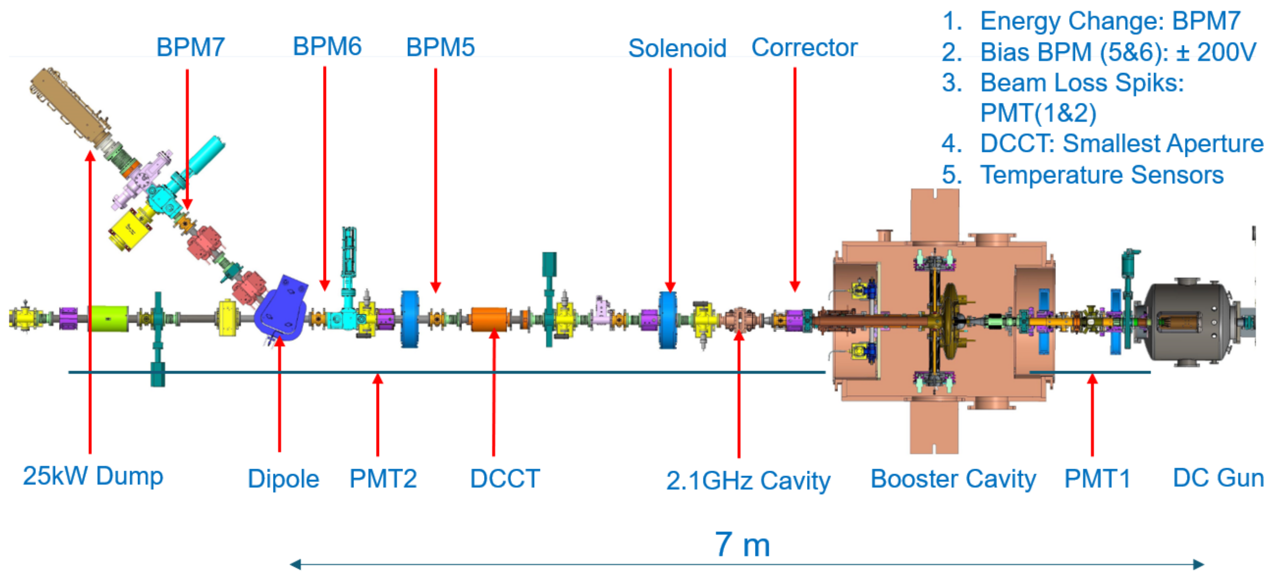


Figure 3: The Layout of LEReC Injection Beam Line.

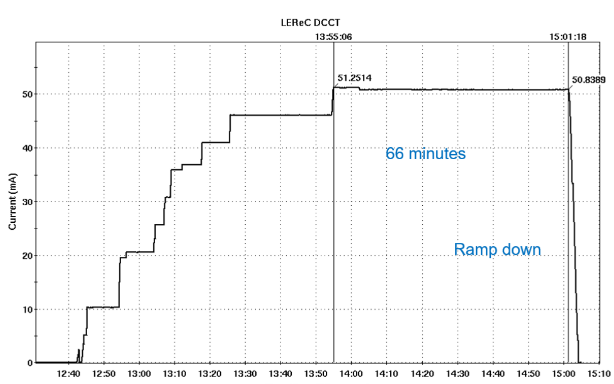


Figure 4: LEReC DC gun 50 mA high current test. The HVPS voltage was 320 kV.

## REFERENCES


[1] A. Fedotov *et al.*, "Experimental demonstration of hadron beam cooling using radio-frequency accelerated electron bunches", *Phys. Rev. Lett.*, vol. 124, p. 084801, 2020.

[2] D. Kayran *et al.*, "High-brightness electron beams for linac-based bunched beam electron cooling", *Phys. Rev. Accel. Beams*, vol. 23, p. 021003, 2020.

[3] S. Seletskiy *et al.*, "Accurate setting of electron energy for demonstration of first hadron beam cooling with rf-accelerated electron bunches", *Phys. Rev. Accel. Beams*, vol. 21, p. 111004, 2019.

[4] S. Seletskiy *et al.*, "Obtaining transverse cooling with non-magnetized electron beam", *Phys. Rev. Accel. Beams*, vol. 23, p. 110101, 2020.

[5] X. Gu *et al.*, "Stable operation of a high-voltage high-current dc photoemission gun for the bunched beam electron cooler in RHIC", *Phys. Rev. Accel. Beams*, vol. 23, p. 013401, 2020.

[6] H. Zhao *et al.*, "Cooling simulation and experimental benchmarking for an rf-based electron cooler", *Phys. Rev. Accel. Beams*, vol. 23, p. 074201, 2020.

[7] C. Liu *et al.*, "Gold-gold luminosity increase in RHIC for a beam energy scan with colliding beam energies extending below the nominal injection energy", *Phys. Rev. Accel. Beams*, vol. 25, p. 051001, 2022.

[8] M. Gaowei *et al.*, "High current performance of alkali antimonide photocathode in LEReC DC gun", in *Proc. ERL'19*, Berlin, Germany, Sep. 2019, pp. 61–64. `doi:10.18429/JACoW-ERL2019-WECOXBS02`

[9] A. Fedotov *et al.*, "Accelerator physics requirements for electron cooler at the EIC injection energy", presented at COOL'23, Montreux, Switzerland, October, 2023.