

Jefferson Laboratory
LDRD Project Data Sheet
Fiscal Year 2018

1. Project Title: Generation and Characterization of Magnetized Bunched Electron Beam from DC Photogun for JLEIC Cooler

2. Project Identifier: PROJ: **LD1805**; PROJ ID: **000001.18.OP.001.003.003.11**; B&R: **LDRD**

3. Principal Investigator: Riad Suleiman

4. Phone Number of Principal Investigator: 757-269-7159

5. Responsible Project/Line Manager: Matthew Poelker

6. Project Start Date: 10/01/2017

7. Expected Project Completion Date: 09/30/2018

8. Type of Work: (basic research, applied research, or development) Basis Research

a. *Basic*= the systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind.

b. *Applied*= the systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.

c. *Development*= the systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development and improvement of prototypes and new processes to meet specific requirements.

9. Project Description: Include a short description of the project and an explanation of the cutting edge, high-risk, high-potential science or engineering.

To achieve the required luminosity at Jefferson Lab Electron Ion Collider (JLEIC), ion beams must be cooled. In general, this is accomplished when an electron beam co-propagates with an ion beam moving at the same average velocity, but different temperatures, where the energy of chaotic motion of the ion beam is transferred to the cold electron beam. The cooling rate can be improved by about two orders of magnitude if the process occurs inside a solenoidal field that forces the electrons to follow small helical trajectories thereby increasing the interaction time with ions and improving the cooling efficiency. This cyclotron motion also provides suppression of electron-ion recombination. Cooling rates with magnetized electron beam are ultimately determined by electron longitudinal energy spread rather than the electron beam transverse emittance as the transverse motion of the electrons is quenched by the magnetic field.

The envisioned JLEIC magnetized cooler is part of the Collider ring and aims to counteract ion emittance degradation induced by intra-beam scattering, to maintain ion emittance during collisions and extend

the luminosity lifetime. To implement cooling at relatively high energy (electron beam energy 55 MeV), the electron beam must be bunched and accelerated in an SRF linac. The JLEIC cooling solenoid is 30 m long providing a 1 Tesla field. Two requirements on the electron beam with noteworthy challenges are related to bunch charge and average current, 3.2 nC and 140 mA, respectively.

One challenge associated with implementing cooling inside the long solenoid of the Collider, is the fringe field immediately upstream of the cooling solenoid. The field lines outside the solenoid magnet introduce very large beam rotation. The ill-effects of this fringe field could be cancelled if the electron beam was born in a similar field, but producing beam rotation in the opposite direction, such that the two cancel.

Although, electron cooling with DC electron beams at low energy has been implemented at many labs, no one has yet demonstrated electron cooling with bunched electron beams, or magnetized cooling. Fermi Lab successfully demonstrated non-magnetized relativistic DC cooling at high energy (4.3 MeV). For Low Energy RHIC Electron Cooling non-magnetized bunched electron beam will be used and eRHIC is planning to use Coherent Electron Cooling.

We plan to demonstrate experimentally many aspects of the magnetized bunched electron beam for the JLEIC cooler, with the notable exception of 140 mA average beam current (limited by the in-house high voltage supplies to 32 mA):

- I. Demonstrate 32 mA magnetized beam
- II. Quantify any difference in lifetime of K_2CsSb photocathode between magnetized and non-magnetized beam
- III. Measure magnetization for a variety of charge, bunch dimensions and solenoid strength guided by JLEIC specifications.
- IV. Quantify the quality of round-to-flat beam transform for a variety of charge, bunch dimensions and solenoid strength.
- V. Demonstrate reliable simulation tools and methods.
- VI. Improve experimental techniques with new machine operation interface.

10. Tie to Mission: Explain the project's relevance or anticipated benefits to DOE's national security missions (energy resources, nuclear security, environmental quality, and science), and to the extent required by law, the mission of other federal agencies.

The goal of this project is to generate a magnetized beam and measure its properties. The impact of the cathode solenoid on the operation of the photogun will be explored. The planned simulations and measurements will provide insights on ways to optimize the JLEIC electron cooler, and help us design the appropriate electron source.

The anticipated benefits are:

- I. Jefferson Laboratory will have direct experience magnetizing a high current electron beam.
- II. We will learn how the applied magnetic field influences the photocathode lifetime.
- III. We will learn about challenges associated with round-to-flat beam transformations at high bunch charge.
- IV. We will benchmark our simulation tools in this new space-charge dominated, magnetized regime.

11. Prior FY Accomplishments and Results: (if applicable)

We finished Year 1 (FY16) demonstrating non-magnetized beam at maximum current of 1 mA and started implementing a long list of improvements. The cathode solenoid was mapped, installed and commissioned. Photocathode preparation chamber, gun HV chamber, cathode solenoid and fully instrumented beamline were all upgraded, commissioned and fully functional. Finally, we were ready to start the experimental measurements outlined in this project. **The highlight of Year 2 (FY17) has been the demonstration of magnetized beam.**

We delivered 4.5 mA magnetized beam for 6 hours with the gun HV at 300 kV and cathode solenoid magnetic field of 1511 Gauss on the photocathode. We also measured beam rotation using the slit and view screen method and these values were used to predicted beam magnetization. There is good agreement between prediction and measurement.

To date, everyone has relied on an invasive technique to measure beam magnetization (a slit and view screen). However, implementing an actual JLEIC electron cooler (e-cooler) will require a non-invasive beam magnetization monitor. While conducting this research, we theorized that a rotating bunched beam will excite RF fields inside a TE011 cavity producing an easily detectable signal that is proportional to the beam magnetization, while such a cavity will be insensitive to other aspects of the beam, such as beam current.

We designed the cavity and will test with beam during Year 3 (FY18) of the LDRD proposal. If proven correct, we imagine cavities distributed around the e-cooler used to non-invasively monitor magnetization. Cavities installed inside the cooling solenoid will ensure that magnetization is completely removed during the cooling process. And cavities installed outside the solenoid will ensure that magnetization is fully restored. The monitors will allow adjustment of machine parameters to optimize cooling in real-time. A patent disclosure entitled "Non-invasive RF Cavity to Measure Beam Magnetization" was filed.

12. Work Proposed for the Current FY and Anticipated /Desired Results:

The electron beam parameters from the injector required to meet the JLEIC cooling specification are unique. Producing low energy, magnetized beam that is space charge dominated has not been previously investigated in depth by the accelerator community. Simulation of different operating scenarios of bunch charge, magnetization and bunch shape will be benchmarked against measurements of emittance and other beam parameters. As the beams will be space charge dominated, there will be some limit to the aspect ratio that can be achieved with the round-to-flat beam transform. Simulation will allow us to quantify how good or complete this can be made for different settings. These results will guide the design of the JLEIC injector in the future.

For the current FY18 and final year of this LDRD project, the proposed work and anticipated results are:

1. Measure mechanical angular momentum vs bunch charge
2. Generate very high currents magnetized beam and study beam transport vs electron bunch charge
3. Design and procure three skew quads

4. Commission TE011 cavity with beam
5. Install three skew quads
6. Generate flat beam with skew quads and measure horizontal and vertical emittances
7. Change to HV Supply of 32 mA and 200 kV
8. Measure photocathode lifetime vs magnetization at 32 mA and 200 kV

13. Project Funding Profile (burdened):

Fiscal Year Request	Amount (\$)
FY1 Budget (FY16)	\$339,211
FY2 Budget (FY17)	\$264,979
Current FY Budget Request (FY18)	\$211,449
Total Estimated Budget	\$815,639