Laboratory-Directed Research and Development Program

FY2016 Annual Report

Thomas Jefferson National Accelerator Facility
Newport News, Virginia

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APPROVALS

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Overview

The Department of Energy (DOE) and the Thomas Jefferson National Accelerator Facility (Jefferson Lab) encourage innovation, creativity, originality and quality to maintain the Laboratory's research activities and staff at the forefront of science and technology. To further advance the Laboratory's scientific research capabilities, the Laboratory allocates a portion of its funds for the Laboratory Directed Research and Development (LDRD) program. This is the third year of an LDRD program at Jefferson Lab, and it is already clear that the program is a real asset to the laboratory. Areas eligible for LDRD support include:

- Advanced study of new hypotheses, new concepts and innovative approaches to scientific or technical problems;
- experiments directed towards "proof-of-principle" or early determination of the utility of new scientific ideas, technical concepts or devices; and
- conception and preliminary technical analysis of experimental facilities or devices.

Within these eligible research areas, the LDRD program is conducted with a scale of effort typically utilizing existing research facilities. The projects can be characterized as:

- Small-scale research and development activities or pilot projects;
- bench-scale research projects; or
- computer modeling, conceptual design and feasibility studies.

We have identified several areas of strategic value to the future of the Laboratory that would benefit from R&D. These particular areas are:

- Addressing the remaining R&D issues for the Jefferson Lab Electron Ion Collider design,
- utilizing heterogeneous architecture in scientific computing beyond LQCD, an essential element of advancing computing to the exascale,
- further development of the detector group in the medical and biological imaging fields, and
- addressing R&D issues relevant for new research directions using our existing facilities.

The TJNAF call for LDRD proposals does not specify particular directions, as we prefer to receive proposals on a wide selection of potential topics. However, relevance to these strategic areas is given strong consideration in the evaluation of the LDRD proposals. In addition, while the LDRD program is viewed as a positive motivator for staff, particularly younger staff, to receive funding and recognition for their work, it is not used specifically for recruitment or retention of staff.

With DOE guidance, the LDRD program enables Jefferson Lab scientists to make rapid and significant contributions to seeding new strategies for solving important national science and technology problems. In addition to building new core competencies that support the DOE missions, the LDRD project proposals may also conduct scientific research and development that support the missions of other federal agencies and/or non-federal sponsors.

The LDRD program supports the Jefferson Lab mission in several ways. First, because LDRD funds can be allocated within a relatively short time frame, Jefferson Lab researchers can respond quickly to forefront scientific problems and capitalize on new opportunities. Second, LDRD enables Jefferson Lab to support and recognize highly qualified scientists in their efforts to carry out world leading research. Finally, the LDRD program also supports new projects that involve graduate students and postdoctoral fellows, thus contributing to our education mission.

Since FY2016 was only the third year of Jefferson Lab's LDRD program, it is too early to identify the long-term consequences on the laboratory of the supported research programs. However, with the completion of the three initial LDRD projects (started in FY2014), three additional projects (started in FY2015), and the first year's effort on two additional projects started in FY2016, it is already clear that the program is delivering results of great interest to our evolving plans for our future science, and that it has been received very positively by the staff as an important avenue for the recognition of excellent ideas and a source of funds for innovative research. As the program evolves, we will track carefully its impact on funding, student and post-doc support, inventions and patents, publications and conference presentations by laboratory staff.

Jefferson Lab has a formal process for allocating funds for the LDRD program. The process relies on individual scientific investigators and the scientific leadership of the laboratory to identify opportunities that will contribute to scientific and institutional goals. The process is also designed to maintain compliance with DOE Orders, in particular DOE Order 413.2B. From year-to-year, the distribution of funds among the scientific program areas changes. This flexibility optimizes Jefferson Lab's ability to respond to emerging opportunities.

Jefferson Lab LDRD policy and program decisions are the responsibility of the Laboratory Director. Under his instructions, the LDRD Program Manager initiates the program each year in February and schedules the supporting activities. The evaluation cycle runs through late September, when the successful proposals are announced, with funds available at the beginning of the fiscal year. We may hold some LDRD funds as unallocated to allow new ideas to be funded later in the year. The evaluation process begins with an optional letter of intent cycle, with the formal proposals due at the end of April. Proposals are reviewed by our Project Review Team (the ALDs supplemented by other experts) and, in cases where it is appropriate, supplemented by outside expert reviewers. Questions raised about individual proposals are given to the principal investigators for their response either in writing or as part of their presentation at a public review session held mid-July. Following that session, the Project Review Team rates and rank orders the proposals based on scientific merit and strategic value to the laboratory's future mission. The Team's recommendations are then sent to the Director, who makes the final decisions. The list is sent to the Jefferson Lab DOE Site Office for concurrence, typically in September, and then the winners are announced (nominally at the end of September). The Project Review Team also generates a written review of each individual proposal that is provided to each principal investigator following the announcement of the winners.

LDRD accounting procedures and financial management are consistent with the Laboratory's accounting principles and stipulations under the contract between Jefferson Science Associates and the Department of Energy, with accounting maintained through the Laboratory's Chief Financial Officer and Budget Office. Jefferson Lab was authorized by DOE to establish a funding ceiling for the FY2016 LDRD program of \$0.80 M, including General & Administrative (G&A) overhead. Scientists submitted eight proposals (including one that was a request for continuation of an ongoing project), requesting about \$2.4 M in funding over a three-year period (\$1.15 M in FY2015). Three projects (including continuation of the ongoing project) were funded totaling \$0.645 M; awards ranged from \$162 K to \$265 K. The actual costs incurred in FY2016 were \$0.613 M, or 0.37% of Jefferson Lab's FY2016 operating and capital equipment budget of \$165,546 M. This amount includes two minor charges expensed in FY2016 for LDRD projects completed in FY2015: a freight charge of \$36 incurred in 2016 for a purchase order received in 2015; and \$727 for an open purchase order commitment on a second FY2015 project for an item that would have been incorporated into the project if received in time, but was not essential for the project achieving its goals. Both of these projects were effectively completed and reported in FY2015, so we have not duplicated the reports here.

Annual Reports for the FY2016 project activities follow.

1.0 Generation and Characterization of Magnetized Bunched Electron Beam from a DC Photogun for MEIC Cooler

Principal Investigators: Riad Suleiman and Matt Poelker

Project Description

To maintain ion beam emittance and extend luminosity lifetime, the Jefferson Lab design of the Electron Ion Collider includes a bunched magnetized electron beam cooler as part of the Collider Ring. This 3-year (FY16/17/18) project aims to generate and characterize magnetized electron beams using a 350 kV inverted-insulator DC high voltage photogun. Measurements of beam magnetization at different bunch charge as a function of laser beam size and magnetic field at the photocathode are planned. The magnetized beam will be transformed into a flat beam using three skew quadrupoles and the transverse emittance ratio will be measured. Results will be compared to particle tracking code simulations. Photocathode lifetime at beam current up to 32 milliamperes will be compared to beam lifetime with no magnetization, to explore the impact of the magnetic field on photogun operation. Combined, these measurements and simulations will benchmark our design tools and provide insights on ways to optimize the electron cooler and choose the appropriate electron source and injector layout.

Accomplishments

Started FY16 with an empty room and built a photogun, an alkali-antimonide photocathode preparation chamber and a diagnostic beamline. The gun was HV conditioned and non-magnetized beam was generated at 1mA and 300 kV. The cathode solenoid magnet was designed, procured, mapped and installed in the front of the gun chamber. The magnet is powered by the new spare Jefferson Lab accelerator dogleg supply. The field at the cathode is 1400 Gauss when using a standard molybdenum photocathode holder, or puck. A carbon steel puck and molybdenum + carbon steel hybrid puck were designed to increase the field at the cathode to 2000 Gauss. Four new pucks were made – two steel and two hybrid. The solenoid field was mapped with these new pucks positioned at the location of the photocathode.

Simulations of the magnetized beam have been used to determine the beamline layout, the design of the emittance and magnetization measurement diagnostics and the concept of a round to flat transformer.

The focus of FY16 work is to be ready to generate magnetized beam in the first quarter of FY17. First, the plan is to upgrade the photocathode preparation chamber to enable photocathode fabrication using a mask, to limit the photocathode active area and reduce beam halo, and to upgrade HV chamber with a new doped ceramic insulator and newly designed HV triple-point shield which will enable photogun operation at 350 kV.

Publications

None

Workshops/Conferences

R. Suleiman, M. Poelker, J. Benesch, F. Hannon, C. Hernandez-Garcia and Y. Wang, *Generation and Characterization of Magnetized Bunched Electron Beam from a DC High Voltage Photogun*, APS April Meeting, Salt Lake City, Utah, April 16–19, 2016.
http://meetings.aps.org/Meeting/APR16/Session/D1.37

Questionnaire

Question	Answer
Will follow-on funding (post-LDRD project) be applied for?	Yes
Source of support for follow-on funding?	DOE SBIR
Has follow-on funding been obtained?	No
Amount of follow-on funding ($K)?	N/A
Number of Post Docs supported by LDRD project?	0
Number of students supported by LDRD project?	0
Number of scientific staff/technical staff hired with LDRD funding?	0
Number of copyrights filed (beyond publications)?	0
Number of invention disclosures filed?	0
Number of patent applications filed?	0

2.0 Nuclear gluons with charm at EIC

Principal Investigator: C. Weiss (Theoretical & Computational physics)

Project Description

A medium-energy Electron-Ion Collider (EIC) would enable novel direct measurements of the gluon density in nuclei using heavy quark production (charm, beauty), as well as measurements of the flavor decomposition of the quark densities in nuclei using light flavor tagging. Such experiments could answer several outstanding questions regarding the nuclear modifications of the nucleon's quark/gluon structure and provide insight into the emergence of the nucleon-nucleon interaction from the microscopic theory of Quantum Chromodynamics. The 2016 LDRD project (continuing in 2017) aims to demonstrate the feasibility of such measurements with EIC, delineate the detector and accelerator requirements, and quantify the physics impact. This includes (a) development and implementation of simulation tools for heavy quark production in deep-inelastic scattering on nuclei at EIC with schematic modeling of the EIC detector performance (charm/beauty reconstruction efficiency, resolution); (b) simulations of measurements of the nuclear gluon densities in the EMC effect region ($x > 0.3$) and the enhancement region ($x \sim 0.1$) using heavy quark probes; (c) simulations of measurements of nuclear quark/antiquark densities with flavor tagging (semi-inclusive pions/kaons); (d) assessment of the theoretical accuracy and physics impact of the nuclear quark and gluon measurements. The results serve to quantify the EIC physics reach and define requirements for future detector R&D. The simulation tools are to be made publicly accessible and can be adapted and extended for other EIC physics studies.

Accomplishments

- **Simulation tool development:** Developed fast stand-alone code for charm cross section estimates using QCD formulas. Adapted HVQDIS heavy-quark Monte-Carlo (MC) from electron-proton scattering at HERA to electron-nucleus scattering at EIC. Adapted existing fixed-target MC for quark flavor separation to collider kinematics at EIC.

- **Process simulations:** Estimated charm production rates and angle/momentum distributions at EIC and mapped their kinematic dependence. Simulated charm reconstruction at EIC using D* channel (no pi/K identification required) and other D-meson channels that become accessible with pi/K identification and vertex detection. Performed all-around assessment of channels/methods for charm reconstruction at large x using EIC's next-generation detector capabilities (particle identification, vertex detection).

- **Physics impact studies:** Assessed sensitivity of nuclear gluon density to charm production observables at large x.

- **Dissemination of results:** Communicated results in several conferences talks and proceedings articles (see below). Made materials available at public project webpage at https://wiki.jlab.org/nuclear_gluons/ Reached out to university/laboratory groups regarding future collaboration (ANL/Arrington, Paris-Orsay/Dupre, others)

- **Overall conclusion:** Gluon measurements with open charm at x ~ 0.1 appear feasible with JLab's EIC design if charm reconstruction can be done with overall efficiency ~< 10%. R&D in 2017 will focus on developing practical reconstruction methods that can achieve such efficiency.

Publications

E. Chudakov, D. Higinbotham, Ch. Hyde, S. Furletov, Yu. Furletova, D. Nguyen, M. Stratmann, M. Strikman, C. Weiss, *Heavy-quark production at an Electron-Ion Collider*, Proceedings of XII International Conference on Beauty, Charm, and Hyperons in Hadronic Interactions (BEACH 2016), 12-18 June 2016, George Mason University, Fairfax, Virginia, JLAB-THY-16-2354 (submitted for publication)

E. Chudakov, D. Higinbotham, Ch. Hyde, S. Furletov, Yu. Furletova, D. Nguyen, M. Stratmann, M. Strikman, C. Weiss, R. Yoshida, *Probing nuclear gluons with heavy quarks at EIC*, Proceedings of 24th International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2016), 11-15 Apr 2016, Hamburg, Germany, JLAB-THY-16-2329 [arXiv:1608.08686] [INSPIRE]

Workshops/Conferences

D. Nguyen, *Nuclear Gluons with Charm at a future EIC*, Photonuclear Reactions Gordon Research Conference, Holderness, NH, 7-12 August 2016 [Conference] [Poster]

D. Nguyen, *Nuclear gluons with charm at a future EIC,* Student poster at 2016 JLab User Group Meeting, JLab, 20-22 June, 2016

C. Weiss, *Charm and beauty production with EIC*, XIIth International Conference on Beauty, Charm, and Hyperons in Hadronic Interactions (BEACH 2016), George Mason University, Fairfax, Virginia, 12-18 June, 2016 [Conference] [Viewgraphs]

Yu. Furletova, C. Weiss, *Probing nuclear gluons with heavy flavors at an Electron-Ion Collider* (presented by R. Yoshida), 24th International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2016), Hamburg, Germany, 11-15 April, 2016 [Conference] [Viewgraphs]

C. Hyde, *Nuclear Gluons with Charm at EIC*, Workshop on Next Generation Nuclear Physics at JLab12 and EIC, Florida International University, Miami, FL, 10-13 February 2016 [Conference] [Viewgraphs]

C. Weiss, *Nuclear gluons with charm at EIC,* EIC User Group Meeting, UC Berkeley, 9 January 2016 [Viewgraphs]

S. Furletov, *Gluons at high x in Nuclei at EIC,* APS DNP Fall Meeting, Santa Fe, 28 October 2015 [Viewgraphs]

Questionnaire

Question	Answer
Will follow-on funding (post-LDRD project) be applied for?	Yes (LDRD project continuing in 2017)
Source of support for follow-on funding?	JLab LDRD
Has follow-on funding been obtained?	Yes
Amount of follow-on funding ($K)?	$185K
Number of Post Docs supported by LDRD project?	1 postdoc (ANL, fractional effort)
Number of students supported by LDRD project?	1 student (U. of Virginia, fractional effort)
Number of scientific staff/technical staff hired with LDRD funding?	0
Number of copyrights filed (beyond publications)?	0
Number of invention disclosures filed?	0
Number of patent applications filed?	0

3.0 Enhancing Simulation Capability for Electron Cooling in MEIC Project

Principal Investigator: He Zhang

Project Description

We proposed to develop a computational platform for modeling and simulation of electron cooling, which addresses (*i*) the bunched electron cooling of coasting ion beam, focusing on the evolution of the macroscopic beam parameters such as emittances and momentum spread, and (*ii*) single pass electron cooling process, focusing on the interaction between individual particles from microscopic view. The new platform will be adaptive to modern high performance hardware.

Accomplishments

The program that simulates the evolution of the macroscopic beam parameters under the intrabeam scattering (IBS) effect and/or electron cooling has been finished. Efficient models have been built for both DC cooling and bunched cooling applied on either coasting or bunched ion beam. The program can calculate an instantaneous expansion rate for the IBS effect and/or cooling effect, and can also simulate the evolution of the beam during the whole process. It has been thoroughly benchmarked with BETACOOL for accuracy and efficiency on various scenarios. The two programs agree very well. By avoiding redundant computation, the new program has achieved much better efficiency than BETACOOL. For a typical JLEIC electron cooling progress simulation, the new program is more than ten times faster than BETACOOL. It now serves as an numerical simulation tool for JLEIC electron cooling study and a platform for further electron cooling related code development. It has been successfully implemented to solve some specific problems for the high energy bunched beam cooler for JLEIC, e.g. the effects on cooling rate due to the electron bunch parameters, such as bunch shape, bunch size, longitudinal phase space correlation, and Larmor emittance. The source code has been released online to the public at https://github.com/zhanghe9704/electroncooling/. A parallel version on the shared memory structure, such as a graphics processing unit (GPU), has been developed. And a further five-time improvement on efficiency has been obtained for expansion rate calculation on one GPU, when compared with the CPU only calculation.

For the single pass electron cooling simulation, the fast solver for the interaction between the charged particles and the symplectic integrator for the dynamic ODEs have been finished. We have developed a new fast multipole method, using traceless totally symmetric Cartesian tensors, to calculate the Coulomb field between charged particles. The algorithm has been extended for other non-oscillating interactions, and a test code has been finished, which shows the algorithm converges for various interactions. An MPI based parallel Hermite integrator has been developed for symplectic tracking of the particles. Numerical simulations on the motion of the particles during the cooling process and the study on the simulation results are in progress.

Publications

None

Workshops/Conferences

H. Zhang, *Progress in Electron Cooling Simulations and Code Development*, JLEIC Collaboration Meeting, Newport News, Virginia, March 29 – 31, 2016

H. Zhang, *Development of The Electron Cooling Simulation Program for JLEIC*, 7th International Particle Accelerator Conference, Busan, Korea, May 8 - 13, 2016.

H. Zhang, *Fast Multipole Method Using Cartesian Tensor in Beam Dynamic Simulation*, Advanced Accelerator Concepts Workshop, National Harbor, Maryland, July 31 – August 5, 2016.

H. Zhang, *Electron Cooling Code Development and Simulation Studies*, JLEIC Collaboration Meeting, Newport News, Virginia, October 5 – 7, 2016

H. Zhang, *Simulation Study on JLEIC High Energy Bunched Electron Cooling*, 2016 North American Particle Accelerator Conference, Chicago, Illinois, October 9 - 14, 2016.

Questionnaire

Question	Answer
Will follow-on funding (post-LDRD project) be applied for?	NA
Source of support for follow-on funding?	NA
Has follow-on funding been obtained?	NA
Amount of follow-on funding ($K)?	NA
Number of Post Docs supported by LDRD project?	0.6
Number of students supported by LDRD project?	0
Number of scientific staff/technical staff hired with LDRD funding?	0
Number of copyrights filed (beyond publications)?	0
Number of invention disclosures filed?	0
Number of patent applications filed?	0