The project title: Demonstration of Active Optical Stochastic Cooling of 1GeV electron beam in CESR

Applicant/Institution:

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Funding Opportunity FOA Number: DE-FOA-0001961

DOE/SC Program Office: High Energy Physics

DOE/SC Program Office Technical Contact: SC.HEPFOA@science.doe.gov or the appropriate Technical Contact listed in Section I under the Supplementary Information subsection in this FOA.

DOE Award Number (if Renewal Application): N/A

PAMS Letter of Intent or Preproposal tracking number (if applicable):

HEP research subprogram(s) as identified in Section I of this FOA:

Innovations in optimization and control of accelerators using methods of differential geometry and genetic algorithms

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## Background and Introduction

Explanation of the importance and relevance of the proposed work as well as a review of the relevant literature. A brief description of research activities conducted by the Principal Investigator and his/her group, including specific roles and responsibilities in collaborative research efforts, and accomplishments and impacts made during the recent past (typically the past three years), is also encouraged. Investigator(s) proposing to conduct research across multiple HEP research subprograms are encouraged to provide their overall plan for such activities, including any transition of effort.

### Background

The goal of this proposal is …

### Unique role of Cornell for the proposed research

Uniqueness of CESR: DLR – each a paragraph

The Cornell Electron Storage Ring (CESR) is uniquely instrumented for the study of innovative storage ring optics and dynamics of electron and positron beams. The ring 768m circumference operates with beam energy ranging from 1GeV to 6GeV with full energy injector. The ~100 independently powered quadrupoles and sextupoles permit a tremendous variety of lattice configurations. The nearly 120 beam position monitors collect turn-by-turn (and bunch-by-bunch) position to inform measurements of orbit, betatron phase advance, transverse coupling, and dispersion and damping rates. The bunch-by-bunch feedback is completely configurable allowing the setting of any combination of the 1281 available 2 nsec RF buckets in CESR for feedback or excitation. The sophisticated control system interface software facilitates real time analysis, modeling and interpretation of beam data, and implementation of optimization and tuning algorithms. The accelerator complex is available for the machine experiments for 2-4 hours each week, depending on requirements of the CHESS x-ray program.

References are included like so [1][2]. Go to Insert -> Cross-references, select Reference type: Numbered item; Insert reference to: Paragraph number.

Previous NSF funding: DLR

An existing NSF grant supports development of an experimental program to demonstrate and explore optical stochastic cooling in CESR. That support has enabled; (1)demonstration of injection and storage of low energy (1GeV) electron beams without damping wigglers. The low beam energy greatly simplifies the requirements of OSC instrumentation and is essential to our test. Prior to these tests CESR had never operated below 4GeV without damping wiggles. (2) Conceptual and engineering design of a helical undulator to serve as OSC pickup and kicker with first harmonic of 800 nm at 1GeV beam energy. The helical geometry attains the requisite wavelength at a lower field than a conventional planar design. (3) Design of chicane style bypass with differential path length of electron beam and undulator radiation of 2mm. (4) Computer model of relevant beam dynamics, as well as generation, propagation, and interaction with radiated electromagnetic fields, that permits detailed simulation of cooling dynamics, including sensitivities to mis-alignments, instabilities, field errors, field variation, etc. (5) assembly of a team of talented young scientists with the expertise to perform this exquisite experiment.

Relation to other efforts worldwide: MBA

Synergy with the Center for Bright Beams: IVB

### Overview of the proposed research

Basically, a summary of what’s proposed **(JMM)**

## Multiple Investigators

In applications with more than one senior investigator, the accomplishments, milestones, and plans of each senior investigator must be clearly identified. Reviewers will be asked to apply the review criterion to the information provided for each senior investigator and these evaluations will be used as input to the funding decisions.

### Synergies between the (co)-PI’s

A short spiel about why 3 PI’s and what each one brings to the table - **JMM**

**Fig. 1**. ***The Wilson Lab accelerator complex on the campus of Cornell Univ.*** *consists of a Linac injector, synchrotron booster and the 768 m circumference Cornell Electron Storage Ring (CESR).*

[Some old text follows] This proposal brings together accelerator science experts and a computational physics theorist with the common goal of extending the way that accelerators are controlled and optimized. The combined expertise includes: in-depth understanding of beam dynamics, not only of storage rings [1], … development of powerful accelerator simulation and optimization tools [3] numerous theoretical tools from statistical… Well instrumented accelerator – the large scale CESR ...

### CESR & Beam Dynamics Modeling

**DLR -** The Wilson Laboratory accelerator complex (see **Fig. 1**) includes a linac capable of accelerating electrons to 300 MeV, and producing and accelerating positrons to 150 MeV. The beam energy is increased to as high as 6 GeV in the synchrotron booster. High energy beams of electrons and/or positrons are transferred to the 768 m circumference Cornell Electron Storage Ring (CESR), where they circulate for many hours. In the high energy/high current mode, CESR is a source of x-rays for the Cornell High Energy Synchrotron Source (CHESS). Low energy operation is reserved for beam physics studies. The storage ring is instrumented with high bandwidth and high precision beam position and beam size monitors, as well as dozens of specialized detectors for measuring the beam dynamics and characterizing the beam environment.

The storage ring has been reconfigured many times since commissioning in 1979 as an electron-positron collider operating in the center of mass energy of the Upsilon system. Subsequent upgrades included modification of interaction region optics, implementation of multiple bunch operation with electrostatic separation, replacement of room temperature with superconducting RF cavities, installation of superconducting wigglers to enhance radiation damping, compact narrow gap undulators for x-ray science and most recently rearrangement of the interaction region to accommodate multiple x-ray insertions. In addition to operation for users as collider and x-ray source, the storage ring has served as a laboratory for accelerator physics and studies of beam dynamics.

### Laser Expertise at Cornell

A paragraph on laser expertise at Cornell. – **ACB**

## Proposed Research and Methods (MBA & others)

Identify the hypotheses to be tested (if any) and details of the methods to be used including the integration of experiments with theoretical and computational research efforts.

### OSC Bypass Requirements for Electrons, including undulators

DLR, MBA





The electron beam circulates counter clockwise in the storage ring. Radiation emitted by electrons in the pickup undulator (centered at 35m,240m in the figure) is extracted from the bend chamber downstream of the pickup, transported across the ring arc, and injected into the bend chamber upstream of the kicker undulator where it transmits a momentum kick to the electrons. The length of the path of the electrons is about 60cm longer than that of the radiation, allowing introduction of optical elements along the flight path, such as lenses and mirrors to focus the light and an amplifier to increase system gain. The propagation time of the light is tuned so that it is coincident with the radiating electrons in the kicker. The 60cm differential propagation length in the arc bypass is to be compared to the 2mm differential length in the conventional chicane bypass in our earlier design as well as in the planned experiment at Fermilab. The extended differential delay allows the possibility of more sophisticated optical elements and a more powerful amplifier.

The momentum kick to the electron in the kicker undulator depends on the arrival time of the electron with respect to the phase of the electric field of the radiation. The optics of the electron transport are designed to couple horizontal betatron amplitude and momentum offset in the pickup to the pathlengh so that the momentum kick in the kicker effects damping. We find that the existing bend and quadrupole magnets in the arc between pickup and kicker permit design of satisfactory cooling parameters. (We may add sextupoles to compensate nonlinearity). Indeed the required modifications to the storage ring are straightforward. The lattice and bypass and pickup and kicker undulator parameters are summarized in Tables I and II. The undulators will be installed in existing straights (recently vacated by electrostatic separators). The bend chambers adjacent to the undulator straights will be modified with in-vacuum mirrors on the outer wall and window on the inner wall for transmission of the undulator radiation.

|  |
| --- |
| Pickup & Kicker Undulator |
| Length [m] | 4.55 |
| Period [m] | 0.325 |
| Geometry | Helical |
| Wavelength[nm] (@1.4kG, 1GeV) | 800 |

Table . Undulator Parameters

|  |  |
| --- | --- |
| Beam Energy [GeV] | 1 |
| Horizontal emittance [pm] x | 0.99 |
| Momentum spread [%] p/p | 0.037 |
| Horizontal cooling range [nm] x | 28.4 |
| Longitudinal cooling range [%] p/p | 0.927 |
| Ratio of horizontal and longitudinal cooling rates x/z | 13.02 |

Table . Cooling and lattice parameters

### OSC Bypass Requirements for Light

MBA, DLR

### Stability Requirements for the Long Bypass

MBA

### Laser Path Feedback

ACB, MBA

### Laser Amplifier

ACB, MBA

## Project Objectives

This section should provide a clear, concise statement of the specific objectives/aims of the proposed project.

All (PIs)

Here we give a concise summary of the specific objectives/aims of the proposed project.

### Reduced Test of Interferometric Stability

Using a dedicated laser to demonstrate ability to stabilize the light path down to 100 nm.

### Install and Characterize Undulators

Period? Number of poles? Planar vs helical?

### Demonstration of Passive Cooling

I.e. able to achieve the required optical phase stability.

### Laser Amplifier

Proceeds in parallel with the above.

### Demonstration of Active Cooling

Ultimate victory.

## Proposed Resources

Identify the resources needed to meet the objectives of the proposed project and accomplish the research goals. Requests for support of any resources in the budgets submitted with the application should be consistent with the scope of research efforts identified in the narrative. Reviewers will be asked to consider if the proposed budgets are reasonable and appropriate to carry out the proposed work and adequately estimated and justified.

This seems like a summary of the budget justification?

## Timetable of Activities

This section should outline, year-by-year, all the important activities or phases of the project, including any activities planned beyond the project period. Successful applicants must use this project timetable to report progress.

DLR

This section outlines all the major activities and phases of our project year-by-year.

Year 1.

Undulator installation & characterization

Bend chamber manufactures

Setup the light path from pickup to kicker locations

Year 2.

Install bend chambers during the downtime

Reduced Test of Interferometric Stability

4.2 Install and Characterize Undulators

4.3 Demonstration of Passive Cooling

4.4 Laser Amplifier

4.5 Demonstration of Active Cooling

Year 3.

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## Appendix 1: Biographical sketches

## Appendix 2: Research Scientists

## Appendix 3: Current and Pending Support

## Appendix 4: Bibliography and References Cited

1. D.L. Rubin, “The Challenges of Ultra-Low Emittance Damping Rings,” in *Proceedings of the 2011 International Particle Accelerator Conference, San Sebastián, Spain*, 2011, p. 956-960.  [PDF (JACoW)](http://accelconf.web.cern.ch/AccelConf/IPAC2011/papers/tuyb02.pdf)
2. D.L. Rubin, “CESR Test Accelerator,” in *Proceedings of Snowmass on the Mississippi 2013, Minneapolis, MN*, SNOW13-00115, [Preprint (arXiv:1308.2325)](http://arxiv.org/abs/1308.2325)
3. D. Sagan, I.V. Bazarov, J.Y. Chee, J.A. Crittenden, G. Dugan, K. Finkelstein, G.H. Hoffstaetter, C.E. Mayes, S. Milashuk, D. L. Rubin, J.P. Shanks, and R. Cope, "Unified Accelerator Modeling Using the Bmad Software Library", Proceedings of the 2011 International Particle Accelerator Conference, San Sebastian, Spain, (2011) 2310-2

## Appendix 5: Facilities & other resources

The Wilson Laboratory accelerator complex includes a linac capable of accelerating electrons to 300 MeV, and producing and accelerating positrons to 150 MeV. The beam energy is increased to as high as 5.6 GeV in the synchrotron booster. High energy beams of electrons and/or positrons are transferred to the 768 m circumference Cornell Electron Storage Ring (CESR), where they circulate for many hours. The storage ring operates over an energy range of 1.5 GeV to 5.6 GeV with circulating currents up to 500 mA. In the high energy/high current mode, CESR is a source of x-rays for the Cornell High Energy Synchrotron Source (CHESS). Low energy operation is reserved for beam physics studies. The storage ring is instrumented with high bandwidth and high precision beam position and beam size monitors, as well as dozens of specialized detectors for measuring the beam dynamics and characterizing the beam environment. All operation and measurements are integrated into the state-of-the-art control system.

## Appendix 6: Equipment

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## Appendix 7: Additional Budget Requirements

N/A

## Appendix 8: Data Management Plan

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## Appendix 9: Other Attachments

N/A