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### **OSC experimental program**

**Brief Conceptual Description:** Optical Stochastic Cooling (OSC) is a method of charged particle beam cooling in which a beam coherently interacts with its own amplified synchrotron radiation. This is accomplished with an optical amplifier and two undulators: one to generate the light, and one to recouple the light back on to the beam. In the second undulator, the beam and the light exchange energy, and in so doing provide a corrective kick to each to each of the phase space trajectories. OSC is a more powerful descendant of the Nobel-winning stochastic cooling process, which enabled the discovery of the W and Z bosons. While a rich theory of OSC has been developed, due to exacting requirements on beam diagnostics, stability, and timing, it has yet to be experimentally demonstrated.

#### **Possible Applications:**

Optical Stochastic Cooling at CESR is a proof of principle experiment to demonstrate reducing beam emittance below its normal equilibrium value. OSC is particularly attractive for heavy particles (hadrons) which are less likely to radiate in normal dipole magnets. Our preliminary analysis indicates that it may prove suitable for implementation in the EIC/eRHIC and become competitive with other cooling approaches (e.g. Coherent Electron Cooling and its sister technique Microbunched Electron Cooling).

#### **Strategic importance for CLASSE:**

This experiment places the accelerator students, postdocs, and staff of CLASSE at the frontier of the accelerator science. It combines the efforts and expertise of three accelerator faculty: storage ring dynamics (Rubin), synchrotron radiation (Bazarov), and ultrafast electron and laser physics (Maxson).. OSC is directly linked to current CBB plans. Additionally, given the fundamental nature and potential applicability of OSC, we believe OSC experiments will serve as an excellent platform for future funding from NSF and DOE.

#### **Description of the experimental program:**

The test of optical stochastic cooling in CESR depends on the development of

1. infrastructure that becomes part of the storage ring,
2. optical components that are external to the storage ring.

I. The storage ring infrastructure includes:

- Two 4.5m long normal conducting helical undulator electromagnets– installed in the straights vacated by the horizontal separators (between Q44 and Q45).
- Undulator power supplies

- Chambers with mirrors and windows (4 total) installed in the dipole magnets adjacent to the undulators, to extract the synchrotron radiation.

## II. The optical components include

- A light path across L3 from the pickup undulator to the kicker undulator. This includes mirrors and light focusing optics.
- An optics table (in L3) with path length equalization mirrors
- Diagnostics (interferometer) downstream of kicker undulator
- Long coherence length laser for alignment
- Pump lasers for active cooling

### **Budget/funding - summary**

The total cost of the 'in ring' infrastructure that is a platform for an ongoing research program, is \$789,943.40 including prototyping, engineering and technical labor, capital expenses, and installation in CESR (see Tim's cost/schedule spreadsheet) Approximately \$300,000 of the OSC part of the Accelerator Technology grant is available to fund this effort.

The cost of the 'optical components' and installation is \$234,263.18 (includes two pump lasers for two stages of amplification (see Matt's spreadsheet) We are planning a grant proposal to DOE to fund the 'optical components'.

## *OSC in CESR: fabrication/installation/measurement plan and timeline*

### **In ring infrastructure**

Fall 2019 – design and fabrication

- Assemble prototype helical undulator
- Design chambers for dipoles B44E/W and B46 E/W with mirrors and windows to transmit undulator radiation
- Design undulator chamber
- Develop (undulator) magnet measurement instrumentation

Fall 2019/Spring 2020 – Machine studies at 6GeV performed on Tuesdays or dedicated machine studies week - time permitting.

- Characterize stability of guide field by measuring reproducibility of turn-by-turn position and beam size data
- Identify (and eliminate) sources of magnet power supply noise
- Develop auto timing capability of BPMs with injected beam
- Enhance single pass precision of BPMs for low current beam

- Calibrate south arc radiation monitors to guide 1GeV injection studies, that is in order to establish that our instrumentation will protect CHESS compact undulators during 1GeV machine studies.

#### Spring 2020 -

- Characterize prototype helical undulator including
  - Field mapping
  - Checking Cooling water flow
  - Temperature stability
- Optics – Phase 0 -Table top test of feedback system – Goal: Demonstrate feedback and frequency/amplitude limitations
  - Optics is available for tests
  - Initial tests with HeNe laser

Characterize ability of optical transport system to preserve short light pulses, and compensate any residual broadening.

#### Spring 2020 – fabrication

- Fabricate dipole chambers for B44E/w and B46E/W
- Machine poles for 2 4.5m long undulators

#### Summer 2020 (Down)

- Replace dipole chambers B44 and B46 (east and west) with chambers equipped with mirrors and windows to extract undulator radiation and masking for synchrotron radiation in CHESS conditions
- Optics - Phase I – Establish light path (round trip transmission of laser light from->B44E->B46E->B46W->B44W->B46W->B46E-B44E -> interferometer). Goal: Demonstrate stabilization of path to 100nm/damping time
  - Install light path from pickup undulator to kicker undulator including mirrors and transport focusing telescope
  - Use feedback system with long-coherence laser to quantify noise (amplitude and frequency of light path)
  - Install optics table (in L3) with rough path-length equalization mirrors. (No amplifiers yet)
  - Install diagnostics downstream of kicker undulator (B44W)

Fall 2020 – Machine studies at 6GeV - performed on Tuesdays or dedicated machine studies week - time permitting.

- Characterize stability of optical path
- Establish optical path of bend radiation (B44E) (extracted in B46E, injected at B46W, extracted at B44W)

#### Fall 2020

- Map field in full length undulators
- Measure hysteresis and residual field in undulators

- Test optical amplifier with OPA light (or any 800nm source)

Winter 2021 (Down)

- Install pickup and kicker undulators in CESR

Spring 2021-machine studies (Tuesdays, time permitting)

- Test undulators with 6GeV (low current) beam – measure effect on orbit and optics
- Establish optical path of undulator radiation from pickup through kicker to extraction mirror in B44W with low current 6GeV beam

### **Optical stochastic cooling**

Demonstration of passive (no amplification) and then active cooling will be performed at 1GeV beam energy. *Machine studies at 1GeV may require additional diagnostics & care to limit potential radiation damage during injection of low energy beam (a capability we desire for future machine studies anyway).*

June 2021 – 2 weeks dedicated machine studies to demonstrate Passive OSC

- Light optics/diagnostics are now compatible with passive OSC
- Implement 1GeV optics, inject and store 20 micro-amp bunch of electrons
- Establish overlap of pickup undulator radiation with electrons in kicker
- Obtain and stabilize interference pattern of radiation in pickup and kicker undulators at B44W

Summer 2021 – down

- Install amplifier in OSC light path

December 2021 – 2 weeks dedicated machine studies to demonstrate Active OSC

- Demonstrate amplification of radiation from pickup undulator
- Demonstrate active cooling
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