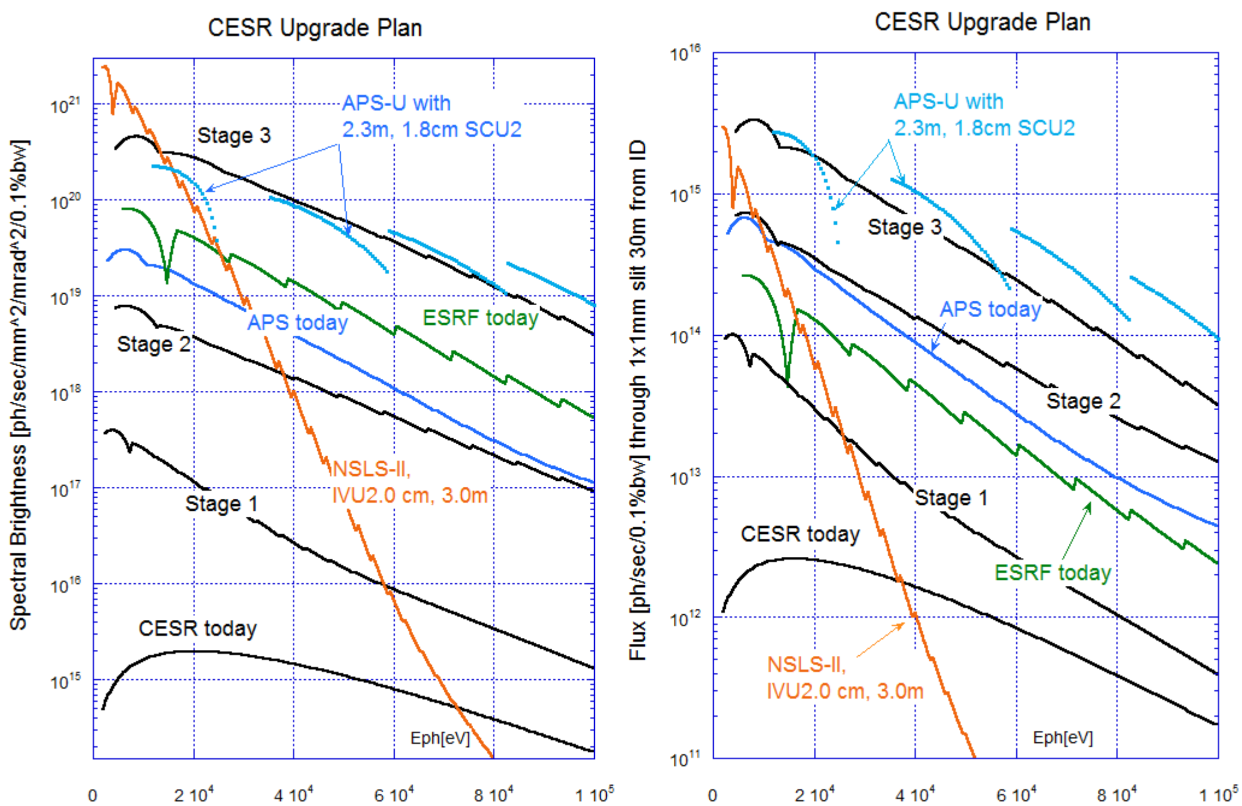
CHESS Improvement Plan
June 11, 2013

Introduction: CHESS is a leader in developing experimental techniques and technology using high energy, high flux x-ray beams, addressing topics ranging from metal fatigue to battery technology to high pressure materials science to the dynamics of biomolecules. This note describes a sequence of upgrades to CHESS and the CESR source that culminate in a 100,000-fold increase in spectral brightness and a 1000-fold increase in flux, on par with the best continuous duty hard x-ray sources world-wide. The spectral brightness and the flux through a pinhole 30m from the source for this sequence of upgrades and other leading sources are shown in the following figure.



CHESS spectral brightness (left) and flux (right) in the F beamline as a function of photon energy, today and after the Stage 1, 2 and 3 upgrades. The performance of the European Synchrotron Radiation Facility (ESRF), the upgraded National Synchrotron Light Source (NSLS-II), and the Advanced Photon Source (APS), currently and after the planned upgrade, are also shown.

Context: The Cornell accelerator complex is based on a full-energy injection synchrotron and the Cornell Electron Storage Ring (CESR). CESR is an unusually flexible machine that has been modified many times to serve the evolving needs of high-energy physics (HEP) and x-ray science. The HEP experiment at CESR has been completed; accordingly, Cornell has examined possible upgrades that could greatly improve photon production at relatively modest costs. This document summarizes the findings to date. These upgrades are compatible with a future Energy Recovery Linac coherent x-ray source.

<u>Upgrade Specifications</u>: The upgrade will be done in four stages that together will convert every current CHESS x-ray beamline into an undulator beamline, increase the spectral brightness by a factor of 50 through reductions in CESR emittance, and finally double the number of x-ray beamlines. The configuration at each stage is given in the Table.

<u>Stage 1</u> – Cornell Compact Undulators (CCU) will be added to three of the six current beamlines (A, F and G), increasing flux by a factor 20 and the spectral brightness by nearly a factor 100 at 30 keV. The CCU design, which employs permanent magnets, was successfully tested at CHESS in 2012. The x-ray optics of these beamlines will also be upgraded to accommodate the more intense beams.

<u>Stage 2</u> – The ten dipole magnets in the south section of CESR will be reconfigured to optimize for x-ray production rather than particle physics. This change, which involves adding vertical focusing components to each one, will reduce the emittance of CESR by a factor of two, doubling spectral brightness, and provide gaps for insertion devices for the remaining beamlines, further increasing brightness. In addition, the A, B and C beamlines will be reoriented to use beams circulating clockwise in the ring so that CESR can operate with a single beam, improving emittance by a further factor two. Following the beamline upgrades, the energy of CESR will be gradually increased from 5.3 GeV to 6.5 GeV.

<u>Stage 3</u> – The remaining dipole magnets throughout CESR will be converted to combined function magnets with dipole, quadrupoles and sextupole components, reducing emittance to 2 nm at 6.5 GeV, and dramatically increasing spectral brightness.

<u>Stage 4</u> – This stage adds six new long, insertion device x-ray beamlines, doubling capacity. The new beamlines would be housed in an extension to Wilson Lab on the east side of the ring. The structural design and construction process of the extension has been examined in a Cornell graduate student Civil Engineering project that resulted in a working plan.

<u>Motivation</u>: X-rays with energy in the 10-100 keV range can characterize the atomic structure of materials. The wavelength is short enough that diffraction can determine the distance between atoms and the energy is well above electron binding energies, minimizing photoelectric absorption and enhancing penetration. With intense beams, these techniques shift from snapshots to movies of materials structures.

The U.S. has a debilitating shortage of the intense, high x-ray energy beamlines required to compete internationally in many areas of economically important science. CHESS and the APS are the only two light sources in the country with the requisite high energy storage rings. A CESR upgrade would enable CHESS to implement competitive, cutting-edge beamlines that would enable the accomplishment of national science goals. In addition, CHESS is the only synchrotron in the nation supporting the research of PhD students specializing in x-ray optics and beamline design, and it partners with the Cornell graduate program in accelerator physics, which accounts for roughly 1/5 of the accelerator physics doctoral degrees awarded in the US.

<u>Cost and Timing</u>: The Stage 1 upgrade will take place in 2014 and 2015 as part of ongoing CHESS operating award. This is possible in part because of the low cost of each CCU.

In 2016, we hope to begin the Stage 2 upgrade, which involves modifying the south sector of CESR (1/6 of the ring) and improving the beamlines to take advantage of the increased brightness. The equipment costs for the CESR modifications are under $4M, making it eligible for the NSF Major Research Instrumentation (MRI) program. The corresponding reconfiguration of the beamlines involves only moving shielding blocks, with no civil construction, but the addition of undulators to the B, C and D lines and upgrading their optics will cost approximately $3.3M each. One or more of these may also be suitable for MRI funding.

The Stage 3 upgrade would take place in 2018 or beyond, and while several designs meet the desired specifications, a detailed cost estimate will depend on engineering that has yet to be done. This upgrade would improve the five sectors of CESR not addressed in Stage 2. The scope of the changes to each sector is more modest than for the Stage 2 upgrade, so that scaling the equipment costs by the number of sectors gives a conservative estimate. After the Stage 3 upgrade, CESR would deliver the full spectral brightness and flux.

The Stage 4 upgrade involves both civil and beamline construction. A plan for the civil construction was developed as a course project by a team of Master's students of Civil Engineering at Cornell under the guidance of a renowned expert on such projects, and the cost was determined in consultation with local contractors and was found to be typical of a university science building. Uncertainties in the above costs are estimated to be 30%.

	Start of op'ns	e+/e- beams	Energy (GeV)	Hor. Emit. (nm)	Single-beam Current	Insertion devices	V/H coupling	β_x F-line	β_y F-line
CESR today	2013	Dual	5.3	130	200 mA	F-line wiggler	0.2%	12	21
Stage 1	2015	Dual	5.3	90	200 mA	1.5m CCU	0.2%	10.9	7.4
Stage 2	2017	Single	6.5	37	250 mA	2.4m CCU	0.2%	As APS	As APS
Stage 3	2019	Single	6.5	2	250 mA	2.4m CCU	0.2%	As APS	As APS