CHESS and Accelerator Sciences

General Information

CHESS, the Cornell High Energy Synchrotron Source, is a key project for the photon science and accelerator physics divisions of CLASSE - the Cornell Laboratory for Accelerator Sciences and Education - located at Cornell University and funded by the National Science Foundation. Photon Sciences encompasses R&D to create X-ray sources and instruments to explore our static and dynamic materials world. After four decades of experience building particle accelerators for colliding-beam physics, faculty, staff and students are now optimizing the Cornell Electron Storage Ring (CESR) for photon production and inventing cutting-edge technologies for a new X-ray source called ERL. Each year over a thousand scientists and students use a dozen X-ray stations for multidisciplinary research in Physics, Chemistry, Biology, Environmental and Materials Sciences, and Engineering. The accelerator physics division advances the frontiers of beam science and develops the physics and technology needed for the production and acceleration of ultra-bright, high power beams for research, medicine and industry. Accelerator physics, the study of how to design, build, and operate these machines, is a field rich with non-linear dynamics, computational physics, engineering, and material sciences.

CHESS X-ray National User Facility

User operations: started from 1980

5.3 GeV 200 mA operations of both electrons and positrons with top-Up operations

3600 hrs of operation annually, with simultaneous operation of 11 experimental stations (5 undulator sources, 2 wiggler sources, 4 high-field bend magnet sources)

Operations Budget: $22M USD in FY2014 from National Science Foundation, National Institutes of Health and Office of Naval Research agencies

~1200 visiting researchers annually, half being early career scientists, post-doctoral associates and graduate students

~300 unique projects served annually from among twice to three times as many proposals

User affiliation: 10% from abroad, 10% from national/public institutes, 76% from universities, 4% from industries

~200 publications/year in refereed journals

Accelerator Sciences

CESR-TA: The CESR Test Accelerator program makes definitive measurements of the beam phenomena determining performance of electron, positron, proton and ion storage rings, and develops methods for overcoming limits

Photoemission electron sources: CLASSE holds records for both beam current and brightness and meets the needs of an Energy Recovery Linac. Innovative photocathode technology seeks even better performance

Superconducting accelerating devices: Cornell advances RF cavity design and materials for highest Q0 and for ultra bright and very high power beams.

Undulators: The Cornell Compact Undulator (CCU) provides a high performance, low cost, tunable energy x-ray source. The helical version offers full polarization control at LCLS

Cornell produces more than 20% of US PhD's in accelerator science, and awarded 5 PhD's in 2013. Nine others in progress

Cornell has 5 regular, fulltime faculty in accelerator science, more than any other US university

40 undergraduates, including some from community colleges, participate in accelerator research each

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Examples of Current Activities

CHESS

The CHESS scientific and technical staff develops forefront research tools and x-ray instrumentation and methods. The facility consists of a mix of dedicated and flexible stations. The flexible stations are easily configured for general x-ray diffraction (wide and small-angle), spectroscopy, imaging applications, etc. Other stations are dedicated to High-Pressure powder x-ray diffraction, pulsed-laser deposition for layer-by-layer growth of surfaces, and protein crystallography. Specialized resource groups at the laboratory included an x-ray detector group; MacCHESS, an NIH supported Research Resource for protein crystallography; a high-pressure diamond-anvil cell support laboratory; a monocapillary drawing facility for making microbeam x-ray optics, and a new program called InSitu to study and model structural engineering materials.

MacCHESS

MacCHESS is the division responsible for Macromolecular diffraction at CHESS. Staff conduct technological research and development as well as supporting users. Numerous publications of biomedical importance result from MacCHESS-supported work, ranging from the first rhinovirus structure in 1985 (Rossmann group), to the Nobel-prize winning K+ channel structure in 1998 and the recent structure of the important regulatory enzyme CD38. In-house developments include hardware, software, and methodological advances that benefit MacCHESS users and the general crystallographic community. Examples include the original cryoloops as well as the recent MiTeGen micromounts for mounting crystals, and important steps in development of the large-area CCD detectors used for data collection throughout the world.

InSitu

In 2014 a new development and training center at CHESS was formed to enable researchers to investigate a broad range of structural and engineering materials questions using high energy x-rays, in-situ specimen environments, and high fidelity computational capabilities. The Insitu (Integrated Simulation and x-ray Interrogation Tools and training for micromechanics) center will: 1) create an enhanced user support structure with a scientific and engineering staff providing state-of-the-art specimen handling, in-hutch instrumentation for high-energy x-ray beams, data collection software, and computational tools for analysis, visualization and interpretation; 2) develop strong linkages to industry to identify challenging materials problems that can benefit from synchrotron data and analysis tools then together develop and refine specific analysis software that can be transitioned to industry for their use in the analysis of synchrotron data; 3) train personnel in industry and academia to become proficient in using synchrotron tools, and incorporate Masters and Ph.D. students in all facets of the facility; and 4) require feedback from industrial users to identify needs and become active participants and partners in the development of future tools and capabilities.

CESR Test Accelerator (CesrTA)

The CesrTA group investigates the physics of ultra-low emittance beams of electrons and positrons. The machine is instrumented for precision measurement of beam trajectories and bunch size. It is equipped with superconducting damping wigglers that allow us to shrink the phase space volume of the 10 billion particle bunch. Specialized detectors are used to measure the growth and decay of the electron cloud. Synchrotron radiation emitted by electrons and positrons in both the visible and x-ray regime is used to measure length width and height of the bunch. We exploit beam instrumentation to study electron cloud physics and electron cloud mitigations, the beam ion interaction, intra-beam scattering, and sources of emittance dilution.

SRF

The SRF group studies the basic phenomena and application of superconductivity in high frequency conditions. The first use of SRF cavities in a high energy physics accelerator was in 1975 at Cornell's 10 GeV synchrotron. From the beginning, and even now, Cornell's SRF group has been a world-wide leader in the field of RF superconductivity and its application to high energy accelerators and synchrotron light sources. Once constructed, SRF cavities go through multiple stages of high-pressure rinsing, electropolishing, and high-temperature baking, all on-site at Newman Lab. After cleaning, cavities are then tested under different loaded conditions, in single-cell and multi-cell arrangements.

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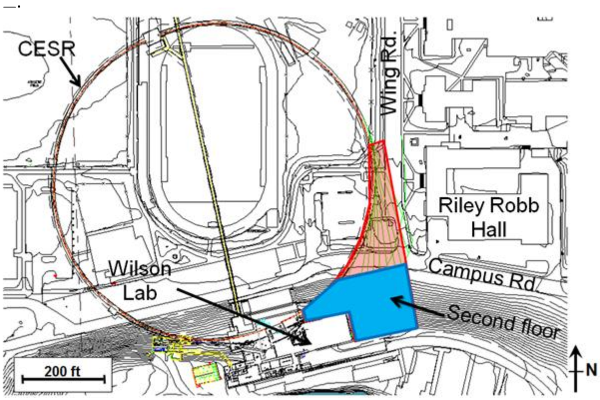
Future Perspectives

CHESS strategic planning is focused on continuing to develop novel experimental techniques and technology using high energy, high flux x-ray beams aimed at addressing modern and emerging scientific and engineering challenges ranging from metal fatigue to battery technology to high pressure materials science to the dynamics of biomolecules. X-rays with energy in the 10-100 keV range can characterize the atomic structure of materials. 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 address a wide array of national science goals.

The upgrade will be done in four stages, first converting current CHESS beamlines to undulator sources, then increasing the spectral brightness by a factor of 50 through reductions in CESR emittance, and finally double the number of x-ray beamlines. These upgrades will incrementally transform the existing storage ring and x-ray beamlines, and be compatible with our ultimate goal to construct a first-of-its-kind high-energy Energy Recovery Linac coherent x-ray source on the Cornell site.

Stage 1 – Cornell Compact Undulators (CCU, figure at right) 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.



Schematic view of an addition to the east side of Wilson lab to house new undulator-fed x-ray beamlines over 100 meters long.

Jason Koski/University Photography

Sasha Temnykh, CHESS senior research associate; Paolo Siboni, an engineer with Italy-based Kyma; and Aaron Lyndaker, CHESS engineer; work on a permanent compact undulator in the Wilson Synchrotron Laboratory annex.

In addition, all the x-ray optics on these beamlines will also be upgraded to accommodate the more intense beams. This scope will be completed in Fall 2014.

Stage 2 – 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, reducing the emittance of CESR by a factor of two, doubling spectral brightness, and providing 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 could be gradually increased from 5.3 GeV to 6.5 GeV.

Stage 3 – 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.

Stage 4 – 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 (figure left).