Accelerator and Detector Research

Portfolio Description

This activity supports basic research in accelerator physics, x-ray and neutron detectors, and advanced x-ray optics instrumentation. Accelerator research is the cornerstone for the development of new technologies that will improve the performance of light sources and neutron spallation facilities. The research explores new areas of science and technologies that will facilitate the construction of next generation accelerator-based user facilities. The program is investing in research leading to a new and more efficient generation of photon and neutron detectors and in x-ray optics, both are overlooked but crucial components in the optimal utilization of the neutron or photon beams. Research includes studies on creating, manipulating, transporting, and diagnosing ultra-high brightness electron beam behavior from its origin at a photocathode to propagation through undulators, and to transporting, analyzing and detecting x-ray beams. Studies on achieving sub-femtosecond free electron laser (FEL) pulses are also undertaken. Demonstration experiments are being pursued in advanced FEL seeding techniques, the study of methods to control the spectral properties of an x-ray self-amplified spontaneous emission (SASE) FEL using amplitude and phase mixing and other optical manipulations to reduce the cost and complexity of seeding harmonic generation FELs. Theoretical and experimental studies on collective electron effects are also supported.

Unique Aspects

Technological advances require new materials and chemical processes for novel and improved sources of energy. The necessary tools enabling control and observation of the temporal evolution of electrons, atoms and chemical reactions demand machines capable of producing high-brightness, high duty-factor, and short beam pulses. The accelerator and detector research carried out by the program aims to improve the output and capabilities of synchrotron radiation light sources and the neutron scattering experiments at facilities that are the most advanced of their kind in the world. These light sources and neutron scattering sources represent the largest collection of such facilities operated by a single organization in the world.

Relationship to Other Programs

- The Accelerator and Detector Research program strongly interacts with BES programmatic research that uses synchrotron and neutron sources. This includes research in atomic physics, condensed matter and materials physics, chemical dynamics, catalysis, geosciences, high-pressure science, environmental sciences, biosciences, and much more.
- There is an ongoing collaboration with the Advanced Scientific Computing Research program to support code development relevant to beam dynamics and to develop tools and codes addressing the exponential growth of experimental data at the BES facilities.
- This activity also interacts with other DOE offices, especially in the funding of capabilities whose cost and complexity require shared support.
- This activity collaborates with the National Science Foundation on Energy Recovery Linac research.
- There are ongoing industrial interactions through the DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) Program awards for the

development of advanced accelerator technology, x-ray and neutron detectors, and x-ray optics instrumentation.

Significant Accomplishments

- This activity was a major supporter of theoretical and experimental studies that led to realization of the Linac Coherent Light Source (LCLS). Theoretical and simulation studies addressed many of the fundamental physics questions concerning SASE FELs and high-brightness beams leading to successful experiments.
- An advanced ^{3}He neutron detector prototype was developed that is capable of measuring pulse height distributions with the highest energy resolution in this mode and covering large areas as required by many neutron source instruments.
- Coded source neutron microscopy has been demonstrated at 25 times magnification, improving resolution and reducing scattering noise in existing limited-resolution imaging detectors.
- A new concept to generate multiple simultaneous spikes in an x-ray FEL spectrum by periodic modulation of the undulator magnetic field has been demonstrated. This allows the generation of two-color spectra and the unique exploration of molecular systems.
- An innovative *in situ* and *in operando* x-ray analysis system was developed to fully explore and analyze the physics and chemistry of photo-cathode materials.
- A program that explores the application of 3D techniques to the difficult problem of integrating x-ray sensors of high-resistivity silicon and readout application specific integrated circuits of low-resistivity silicon has achieved the first successful three-dimensionally integrated chip for photon science. When fully developed these sensors will be capable of handling synchrotron radiation at energies up to 100 keV with high energy resolution.
- As part of our goal to encourage the development of photocathode guns capable of generating low-emittance beams at high repetition rates, a normal conducting very high frequency electron gun was successfully built under the specifications of repetition rates up to 1 MHz, small beam size, and high charge per bunch.

Mission Relevance

The Accelerator and Detector Research program supports the most fundamental of research needs to characterize and control materials at the atomic and molecular level. In order to understand, predict, and ultimately control materials properties, it is necessary to determine the atomic constituents of materials, the positions of the atoms in materials, and how the materials behave under the influence of external perturbations such as temperature, pressure, chemical attack, and excitation by photons, electrons, and other particles. The activity seeks to develop new concepts in accelerator science to be used in the design of accelerator facilities for synchrotron radiation and spallation neutron sources that will provide the means necessary to achieve a fundamental understanding of the behavior of materials. Also supported is the development of higher-precision, more efficient detectors capable of acquiring data several orders of magnitude faster than state-of-the-art detectors, and advanced x-ray optics that offer higher precision and higher accuracy in order to fully exploit the fluxes delivered by the new facilities.

Scientific Challenges

- Development of new accelerator concepts crucial to the design and upgrade of synchrotron light sources and neutron scattering facilities.
- Sponsor research to support the BES Advisory Committee recommended light source to provide high repetition rate, ultra-bright, transform limited, femtosecond x-ray pulses over a broad photon energy range with full spatial and temporal coherence.
- Development of components suitable for diffraction-limited storage rings with beamlines, optics, and detectors compatible with the increase in brightness afforded by upgraded storage rings.
- New detectors must be developed that are capable of using the high data rates associated with high brightness sources thus increasing beamline efficiencies and user throughput.
- Low-background, high-spatial-resolution neutron detectors, and replacement of Helium-3-based detectors.
- Development of x-ray optics instrumentation that can compensate for detector limitations to enhance the combined spatial, temporal and energy resolution of experimental data.
- Special emphasis on R&D leading to more energy efficient machines and devices that go beyond the most common methods of particle acceleration.

Projected Evolution

X-ray and neutron scattering will continue to play a central role in the growth of BES programmatic science. The Spallation Neutron Source (SNS) will be the most powerful neutron spallation source in the world for years to come. Future FEL light sources are expected provide high repetition rate, ultra-bright, transform-limited, femtosecond x-ray pulses over a broad photon energy range, with full spatial and temporal coherence.

Two major components will be required for the advancement of material science: the production of photon beams with increased average flux and brightness and the detection tools capable of responding to the high photon beam intensity. The first component will require higher repetition rate photocathode guns and radiofrequency (RF) systems, and photon beams of enhanced temporal coherence, such as produced by improved seeding techniques or x-ray oscillators, in the case of FELs. Detectors will require higher computational capabilities per pixel, improved readout rates, radiation hardness, and better energy and temporal resolutions. Additionally, R&D will be required to produce ultrafast beam instrumentation capable of measuring accurately femto and attosecond bunch lengths. Higher neutron flux capabilities at the SNS will demand high intensity H^- currents, possibly provided by the development of high power and high frequency lasers, and detectors designed for advanced neutron imaging with very high throughput. Finally, R&D emphasizing energy efficient machines and strong collaborations among the national laboratories and universities will allow a cost-effective, coordinated, and interdisciplinary approach to research and development in accelerators, detectors and x-ray instrumentation.