Accelerator and Detector Research

Portfolio Description

This activity supports basic research in accelerator physics and x-ray and neutron detectors. Accelerator research is the corner stone for the development of new technologies that will improve 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 aggressively in research leading to a new and more efficient generation of photon and neutron detectors, an overlooked but crucial component in the optimal utilization of the provided beam. Research includes studies on creating, manipulating, transporting, and diagnosing ultra-high brightness beam behavior from its origin at a photocathode to propagation through undulators. Studies on achieving sub-femtosecond (hundreds of attoseconds) free electron laser (FEL) pulses are also undertaken. Demonstration experiments are being pursued in advanced FEL seeding techniques, such as echo-enhanced harmonic generation and other optical manipulations, to reduce the cost and complexity of seeding harmonic generation FELs. Theoretical and experimental studies on collective electron effects, such as micro-bunch instabilities from coherent synchrotron and edge radiation, and development of beam bunching techniques, such as magnetic compression or velocity bunching, are supported. Research on fast instruments to determine the structure of femtosecond electron bunches, and detectors capable of acquiring x-ray and neutron scattering data at very high collection rates are also promoted.

Unique Aspects

Technological advances demanded by novel and improved sources of energy require new material and chemical processes possible only through a fundamental understanding and characterization of the structure and dynamics of matter at the molecular and atomic levels. 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. This research activity seeks to develop concepts to enable the new machines. 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. Together, they serve more than 11,000 users annually from academia, Department of Energy (DOE) national laboratories, and industry. The number of users has more than tripled in the past decade and may more than double again in the next decade as current facilities and those under construction are fully instrumented. 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 R&D 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, engineering, biosciences, and much more. There is an ongoing collaboration with the Advanced Scientific Computing Research (ASCR) to support code development relevant to beam dynamics. The activity also interacts with other DOE offices, especially in the funding of capabilities whose cost and complexity require shared support. The Brookhaven National Laboratory Advanced Test Facility (ATF) is jointly funded by the High Energy Physics Program and BES. There is also collaboration with the National Science

Foundation (NSF) on machine physicsresearch, and a coordinated effort between DOE and NSF to facilitate the development of x-ray detectors. There are ongoing industrial interactions through DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) Program awards for the development of advanced accelerator technology and x-ray detectors.

Significant Accomplishments

This activity has been a major supporter of theoretical and experimental studies that led to the realization of the brightest light source available, the Linear Coherent Light Source (LCLS). Theoretical and simulation studies supported by the activity have addressed many of the fundamental physics questions concerning Self-Amplified Spontaneous Emission (SASE) FELs and high-brightness beam leading to remarkably successful experiments and the demonstration that high peak beam brightness is possible with a very low average current, as realized at LCLS. Bunch compression and coherent radiation studies at ATF using a chicane have led to the first observation of multi-Tera Hertz (THz) coherent edge radiation. Measurements of phase space distortions from acceleration fields have been carried out and are a basis for FEL bunch length diagnostics. A holographic THz Fourier transform spectrometer test bed at the Jefferson Laboratory FEL facility was completed, the first required step for developing a single shot device to completely characterize bunch shapes. Tests have shown very satisfactory results on the development of an advanced ^{3}He neutron detector prototype that is capable of measuring pulse height distributions with the highest energy resolution in this mode. The latter is an example of research relevant to neutron scattering facilities, in particular to the Spallation Neutron Source (SNS). Gigabyte per second data rates will be achievable that will provide neutron imaging with position resolution less than 1 mm, very high throughput, and the capability to cover large areas as required by many neutron source instruments. A proof-of-principle demonstration of Echo-Enabled Harmonic Generation is being carried at the SLAC National Accelerator Laboratory, whereby high harmonics of the original beam are generated by beam manipulations that produce high up frequency conversion and relatively small energy modulation. The resulting beam can generate a fully coherent and short wavelength FEL radiation, and the scheme has the potential to enhance greatly the performance of FEL machines while reducing their cost. The program sponsors the development of high-gradient Super Conducting RF accelerating structures that capable of handling high average beam current required by high-average brightness beams featuring harmonic damping of higher order modes to avoid beam breakup and degradation of beam quality, and optimized performance with respect to RF, cryogenics, and cryostat engineering to minimize costs. A program is underway that explores the application of 3-D techniques to the difficult problem of integrating X-ray sensors of high-resistivity silicon and readout Application Specific Integrated Circuits of low-resistivity silicon. If successful, these sensors will be capable of handling synchrotron radiation at energies up to 100 keV and 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 (VHF) electron gun is being built under the specifications of repetition rates up to 1 MHz, small beam size, variable bunch length for controlling space charge effects, and capable of high charge per bunch. The program also sponsors five Young Career award recipients associated with four DOE laboratories and one university, and three Presidential Early Career Award Scientists and Engineers (PECASE) recipients.

Mission Relevance

The Accelerator and Detector R&D program supports the most fundamental of research needs, i.e., the need 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 detectors capable of acquiring data several orders of magnitude faster than the state-of-the-art detectors in order to exploit fully 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.
- Start-to-end simulations of the SASE electron source, transport, and SASE FEL will give details of the physics mechanisms and provide benchmark models for x-ray FELs.
- Experimental studies must be conducted on the creation and transport of ultra-high brightness electron beams to drive SASE photons.
- 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.
- Detectors must also be developed that are capable of acquisition of all required x-ray data from a single femtosecond LCLS pulse.
- Development of injector capable of delivering high peak current, low transverse emittance, and high-repetition rate required by next generation light sources.
- Comprehensive study of cathode materials of good quantum efficiency and low intrinsic emittance.
- Special emphasis in R&D leading to more energy efficient machines and devices that go beyond the most common methods of particle acceleration that are in general not optimized for electric power utilization.

Projected Evolution

X-ray and neutron scattering will continue to play a central role in the growth of BES programmatic science. SNS will be for years to come the most powerful neutron spallation source in the world. It is important to be prepared for full use and judicious increases in the capabilities of the SNS as recommended by all advisory committees to DOE. The peak brightness of the LCLS is 10 orders of magnitude greater than current synchrotrons; the light is coherent or “laser like” enabling many new types of experiments; and the pulses are short (70 femtoseconds in standard operation, with planned improvements that will further reduce the pulse length) enabling studies of fast chemical and physical processes. These facilities will need continuous growth in terms of accelerator upgrades, and x-ray and neutron detectors capable of fully exploiting their high fluxes and brightness.

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 RF systems, and photon beams of enhanced temporal coherence, such as produced by improved seeding techniques or X-ray oscillators, in the case of free-electron lasers, or high brightness injectors with enhanced beam manipulation capabilities, in the case of energy recovery linacs. 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, and photon optics bandwidth. R&D will also be needed to explore cross-cutting technologies for laser generating EUV/XUV radiation, laser-plasma accelerators offering compact electron sources and extremely high accelerating fields, and laser-driven vacuum structures capable of ultrafast time scales and Terawatt peak power. Higher neutron flux capabilities at the Spallation Neutron Source 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. The community has indicated the need for shared test facilities of comprehensive general purpose where different approaches and architectures can be demonstrated at lower cost and more efficiency than specific test beds at every institution. Finally, R&D emphasizing energy efficient machines and strong collaborations among the national laboratories and laboratories and universities will allow a cost-effective, coordinated, and interdisciplinary approach to research and development in accelerators and detectors.