ACCELERATOR & BEAM PHYSICS

FACULTY

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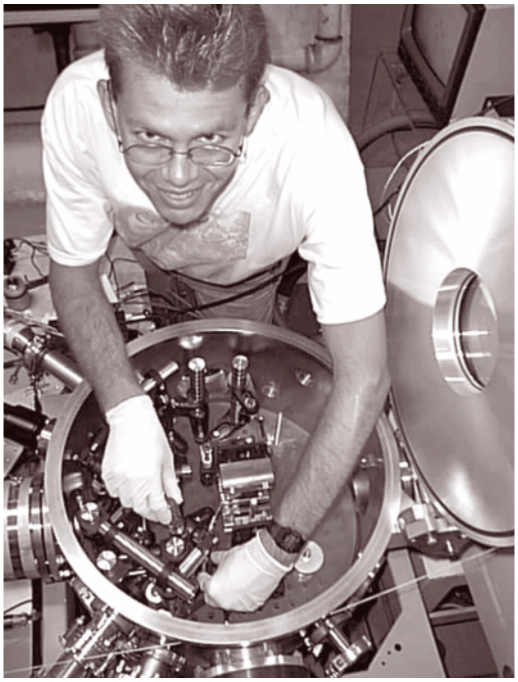
Accelerator physics is a branch of physics that provides innovations to building accelerators which, at SLAC, include accelerators for high energy physics and accelerators for research based on synchrotron radiation and free electron lasers.



Graduate Student Preparing Laser Accelerator Experiment.

High-energy physics is an experimental science whose reach is limited by the performance characteristics of accelerators, particularly their energies and intensities. To further our understanding, accelerators are being designed and constructed to expand both the energy reach and to increase the event rates necessary for precision measurements of rare processes. For example, to understand the origins of electroweak symmetry breaking, many physicists are looking toward multi-TeV lepton collisions. However, the highest energy e^+e^- collider (LEP at CERN) operated in the 0.2 TeV energy range. Similarly, to understand the origins of CP violation, physicists are working to produce collisions roughly 100-times more frequently than has been previously possible. This disparity reflects the status of accelerator physics as it is understood at this writing. While the ultimate reach into the sub-atomic world, and therefore the future of high energy physics, has yet to be decided, it is clear that it will greatly depend on invention and discovery in the physics of beams and the technology of accelerators.

At SLAC, accelerator physics innovation has led to breakthrough discoveries in high-energy physics. The saga began with the Two-Mile Electron Accelerator, a bold and ambitious project for the time, which resulted in the first direct evidence for quarks in the nucleon. Next was the development and construction of the electron-positron collider, SPEAR, resulting in the discovery of the ψ meson and the τ lepton. More recently, the transformation of the SLAC Two-Mile Electron Accelerator into the 100-GeV Stanford Linear Collider (SLC), resulted in the first accelerator-measured limit of three quark generations and the best single test of electroweak theory, as well as paving the way for a much higher energy e^+e^- colliders. Using the knowledge gained from the SLC design and operation, physicists around the world have been studying the next-generation of linear colliders. These facilities would have energies in the center-of-mass of roughly 1 TeV, about ten times that of the SLC.

In addition to making breaking discoveries in high-energy physics, the e^+e^- collider SPEAR also pioneered the study of a new field of research using beam-based synchrotron radiation which has wide-ranging applications in applied physics, biology, chemistry, and material science. The success of SPEAR as a synchrotron radiation facility spawned the idea to upgrade and redesign it in the same tunnel. This new synchrotron radiation facility, now called SPEAR-III, is now commissioned and is functioning extremely well. Furthermore, the SLC technology also stimulated an exciting new accelerator project called Linac Coherent Light Source (LCLS). This ultra-bright Free Electron Laser, (FEL), source of very short wavelength x-rays promises to become a flagship of research in various other fields such as biology, chemistry, and condensed-matter physics. The FEL uses a series of short (~centimeter) magnets to wiggle a beam of relativistic electrons transversely causing them to radiate. The wavelength of the radiation is approximately the period of the wiggler structure divided by gamma squared, where gamma is the energy of the electrons in units of the electron's rest energy. At 15 GeV, the nominal LCLS energy, this produces x-rays of a few tenths of a nanometer with a wiggler perion of a few centimeters. The wavelength is tunable by changing the electron beam energy.

THE INTERNATIONAL LINEAR COLLIDER PROJECT (ILC)

The field of particle physics stands at the threshold of a new era of discovery. Exploration of the energy frontier is at the center of this program. The next high-energy accelerator, the Large Hadron Collider, is under construction at CERN, Geneva, Switzerland, and will collide protons-on-protons with a center-of-mass energy of 14 TeV. While this accelerator will do much to explore physics at the TeV-scale, the international high-energy physics community has concluded that a high-energy high-luminosity e^+e^- linear collider is needed to complement and provide more rigorous quantification of physics seen or not seen at the LHC.

An e^+e^- linear collider accelerates bunches of electrons or positrons in long (>10 km) linear accelerators to prevent synchrotron radiation energy losses from the ultra-relativistic particles. These multi-MW beams are then focused to nanometer-sized spots with densities of 10^{22} e^-/cm^3 to attain the desired collision rates. Although the feasibility of the required technologies has been demonstrated, the technology remains extremely challenging, and the construction of such a multi-billion dollar experiment will be an enormous undertaking and there are innumerable topics that need further research and development.

SLAC plays a major role as a contributor to the international collaboration to design and build the high-energy high-luminosity linear collider. In the past decade, linear collider designs were based on two distinctly different technologies; one utilized room temperature high-gradient RF structures and the other utilized superconducting RF structures. SLAC's primary design effort has been centered on the room temperature approach. In August 2004, after detailed review, an international sub-panel of the International Committee for Future Accelerators (ICFA) formally recommended that the accelerating structures of the International Linear Collider (ILC) be based on the use of superconducting technology. As a result of this decision SLAC is now adjusting its research programs to address this new emphasis. Having built and successfully operated the world's one and only linear collider, the Stanford Linear Collider (SLC), with a center-of-mass energy of 100 GeV, SLAC is an undisputed world center of expertise on linear colliders. The frontline research on linear collider design and its physics remains one of the major efforts at SLAC.

The R&D program at SLAC that is now emerging for the superconducting ILC will include the following elements: accelerating structure optimization, the RF generation,

A 75 MW Prototype Klystron Producing 11.4 GHz rf Power for the Linear Collider R&D Program.

handling, and its efficient coupling to the structures, and the numerical modeling of various RF components. The research program will also include design and optimization of the electron gun and positron source, the storage and damping ring, and the complex final focus systems. These areas require the resolution of many challenging and demanding accelerator physics issues such as beam emittance control and stability. It is also necessary to address the issue of how to handle and diagnose the extremely small beam size and how to collimate the beams to eliminate their undesired tails.

Many of these topics require a combination of hardware and software development as well as computer simulation. There are many test facilities at SLAC that have been developed for these studies. Research originally conducted for the room temperature rf structures, although not applicable for the superconducting ILC, contain elements that remain of fundamental interest for other accelerator applications and for fundamental accelerator physics research. A part of this research effort is expected to continue.

PEP–II and Advanced B-Factory Research

Another aspect of high-energy physics at SLAC is the PEP-II B-Factory where two storage rings with asymmetric energies collides two beams in a single interaction region to study CP violation and rare decays of B mesons. In PEP-II, the luminosity limits of a positron-electron collider are being significantly extended beyond the present world limits. The B-Factory employs many state of the art accelerator physics techniques which have recently been developed but not all put to experimental test. Additional studies investigate significant future luminosity improvements.

Upgrading PEP-II involves ongoing research areas covering a broad range of topics. Beam-beam interactions will ultimately limit PEP-II performance, and studies to increase the limits are underway. The beam currents stored in PEP-II are in the one- to two-ampere range, and the vacuum system can handle up to three amperes. Thus, studies of high-current beam loading in the rf systems are important. These high beam currents are nominally distributed over 1650 bunches introducing multi-bunch instabilities, which in turn are cured by digital feedback systems which work on the nanosecond time frame. Future improvements will need better feedback systems. The very small spot sizes at the collision point force the magnetic lattice design to delicately correct the chromatic beam optics in PEP-II. Improvements in the chromatic corrections will lead to increased luminosity. Far-term future improvements will likely involve a redesign of the interaction region which is presently one of the most advanced in the world. This area needs new and innovative ideas.

Advanced Accelerator Research

Beyond the ILC, and to reach center-of-mass energies of 5 TeV and beyond, collider scalings indicate that a linac and final focus based on current ideas would be of enormous scale, and incur expenses greater than society would support. At these energies, there is no present technology adequate to the task and new ideas are required. Theoretical and experimental advanced accelerator research at SLAC is presently focused in a number of areas:

development of a 1m long, 1 GeV electron accelerator. Design, fabrication and testing of mm-wave accelerator structures, power sources, and a 1 GeV beam-driven plasma accelerator in the Final Focus Test Beam Facility. Commissioning of a laser-driven linac;

field-emission, breakdown, dark currents, and associated materials studies, for high-gradient accelerating structures;

periodic permanent magnet-focused klystrons at cm and mm wavelengths. Alternative high-power klystrons including sheet-beam or multiple-beam klystrons and magnetrons;

overmoded, multi-moded, and quasi-optical rf components, for high-power compression and distribution in high-gradient accelerators;

active high-power rf switches for pulse compression, based on laser-triggered silicon, diamond switches, semiconductors, ferrites, and plasmas;

high-gradient structure design, precision manufacture, and QC procedures;

collective and non-linear beam dynamics, including the study of beam instabilities and methods to control or to feedback damp instabilities;

astro-beam physics exploring the extreme intensity and energy density contained in a strongly focused high-energy electron beam;

the Orion proposal, to continue the present round of research into advanced acceleration technologies using lasers, plasmas and high-energy electron and positron beams.

GRADUATE STUDIES IN ACCELERATOR AND BEAM PHYSICS

As an academic discipline, beam physics is interdisciplinary, calling on the physics and techniques often found in the areas of applied physics, electrical and mechanical engineering, high-energy physics, laser science, and materials science. Thesis work has included subjects as diverse as the design, construction, and commissioning of electron guns, and beam dynamics from Lie algebraic or quantum mechanical perspectives. From the realm of advanced metallurgy and materials science, to the first-principles problems of quantum electrodynamics in media, beam physics includes problems and challenges from every area of the physical sciences. The research topics at SLAC run the gamut of physics for contemporary and advanced accelerators: nonlinear dynamics, collective effects, studies of multibunch instabilities, advanced beam feedback systems, real-time machine modeling and operational analysis, high-power RF systems, mm-wave accelerator fabrication, assembly, bench and high-power test, and plasma and laser acceleration techniques.

Graduate research in beam physics at SLAC is for those who are taken with the idea of exploration into the most remote realms of the universe, and who have the desire to invent the machines of the next millennium. For such physicists, SLAC is a unique and challenging research environment. SLAC has the largest beam physics faculty in the world with 10 members who, along with approximately 50 staff physicists and roughly 15 graduate students from Stanford and elsewhere, pursue beam physics research of some kind at SSRL, the SLC, and the B Factory, or for ILC and advanced accelerator research.

SLAC facilities available to provide general support for beam physics research include departments devoted to vacuum, metrology and precision assembly, power conversion, control systems, software, and klystrons, as well as special purpose facilities for hydrogen brazing, plasma deposition, surface studies, digital electronics, and RF, microwave and mm-wave bench measurements. Specific beam lines available for experimentation include the SLAC Two-Mile Accelerator, a 500 MeV test accelerator, two 2200 m circumference storage rings, one storage ring employed as a light source with two 100 MeV accelerators housed in its injector vault.