High Energy Physics at Berkeley Lab

The High Energy Physics Program at Berkeley Lab includes a strong experimental and theoretical particle physics and cosmology program in the Physics Division and a leading accelerator physics and technology program in the Accelerator and Fusion Research Division (AFRD).

The Physics Division

The program of the Physics Division is focused on the most profound questions in basic science. Our program seeks to understand the origin and fate of the universe and to determine its basic constituents.

What is the nature of the dark energy?

Our picture of the origin and nature of the universe has been transformed in the past few years by the first precision measurements of the fundamental cosmological parameters. Contrary to the expectations of the theorists, experiments concluded that the universe is expanding at an increasing rate. These results sparked a number of new theories regarding the so-called “dark energy” that is driving the accelerating expansion of the universe. Over the next 20 years, Berkeley Lab scientists, in collaboration with a broad community, will seek to discover the nature and character of the dark energy through studies of distant supernovae, studies of the cosmic microwave background, and, perhaps, other techniques as yet undiscovered.

What is the origin of particle mass?

In the standard model of particle physics all of the masses arise from interactions of the particle in question with a "Higgs field". The simplest implementation of this Higgs field involves the existence a single new particle, the Higgs boson, whose mass is not predicted by the theory but whose interactions are. In order to understand the mass generation mechanism it is necessary to discover these Higgs bosons and any other associated particles (such as those predicted in models of super symmetry) and to measure their couplings to the other particles of the standard model. The LHC will search for the Higgs boson and provide data of enormous significance in improving our understanding of the fundamental properties of matter. Additional experiments will be required to observe all of the decays of Higgs bosons and other associated particles and to measure all of the couplings precisely. Some of these could be accomplished by upgrading the LHC in either luminosity or energy. When a high-luminosity TeV-scale linear electron-positron collider (ILC) is constructed, it will complete the picture by permitting the precise measurement of the properties of the Higgs bosons and other new particles.

What is the dark matter?

Over the next 20 years, Berkeley Lab scientists, in collaboration with a broad community, will seek to discover the nature of the dark matter through a combination of accelerator-based direct production searches, studies of weak lensing of distant galaxies, studies of the cosmic microwave background, and possibly other techniques. The accelerator-based searches will occur at the Tevatron, the Large Hadron Collider, and, in the longer term, at the International Linear Collider. All indications point to dark matter particles existing at the TeV mass scale, and these accelerators have the capability to explore this mass scale, uncover these new particles, and measure their properties in detail. Advanced accelerator technology will need continuous development to build and fully exploit the capability of these machines. Observations of weak lensing will complement the accelerator-based measurements and cosmic microwave background measurements to confirm that the large-scale characteristics of dark matter match the terrestrial observations.

What is the origin of the Matter-Antimatter Asymmetry?

In the early universe, matter and antimatter were created in equal amounts: pairs of electrons and positrons, pairs of quarks and antiquarks, and so on. Today, all we find in the universe is the matter that makes up the atoms of stars, planets and postgraduate students. All the antimatter has disappeared. The excess of matter over antimatter is thought to have built up during the evolution of the universe. It can arise from a subtle, but fundamental difference between the properties of matter and antimatter, known as CP violation. In order to understand better the differences between matter and antimatter we need to study CP violation thoroughly by making precise measurements of its effects. Standard electroweak theory predicts that these effects should be larger in certain decays of B mesons. Using the BaBar detector at SLAC, Berkeley Lab scientists and their collaborators are analyzing many tens of millions of B decays to study the phenomenon and have observed the first compelling evidence for CP violation outside the kaon system.

Are there additional space-time dimensions?

Over the next 20 years, Berkeley Lab scientists, in collaboration with a broad community, will seek to discover the existence of large extra space-time dimensions through a program of accelerator-based searches. The accelerator-based searches will occur at the Tevatron, the Large Hadron Collider, and, in the next decade, at the International Linear Collider. If the large extra dimensions or new quantum dimensions are a key element in the explanation of the origin of mass, these accelerators have the capability to discover and measure in detail the properties of the extra dimensions.

How did the Universe begin?

Over the next 20 years, Berkeley Lab scientists, in collaboration with a broad community, will endeavor to open a window on the emission of gravitational radiation in the first moments of the Big Bang through the detection of the polarization of the microwave background. The polarization information retains a signal from the primordial gravitational radiation that should be detectable with sufficient advances in detector technology.

What are the masses of neutrinos, and how have they shaped the evolution of the universe?

Over the next 20 years, Berkeley Lab scientists, in collaboration with a broad community, will seek to discover the pattern of masses and mixings of the neutrinos. The next steps are to pursue experiments in double beta decay to determine if the neutrino is its own anti particle, and additional reactor-based measurements to determine the value of the unknown mixing angle, θ_{13}. If θ_{13} is sufficiently large, this will open the way to a large accelerator-based program to search for matter –antimatter asymmetries in the lepton sector. Such asymmetries may be the source of all matter in the universe. Detector facilities at an appropriate reactor site are essential to reactor-based θ_{13} measurements. Double beta decay requires a deep underground laboratory.

Accelerator and Fusion Research Division

AFRD is dedicated to continuous strengthening of our core expertise in selected areas of accelerator physics and technology and applying that expertise to the evolving national needs identified in the Office of Science Strategic Plan and Twenty Year Outlook. To be successful our strategy must

1) identify those competency areas that are critical to the success of Office of Science programs and projects,
2) ensure that we build and maintain a world-leading cadre of expertise and supporting infrastructure,
3) offer new opportunities to open areas of transformative science and technology.

AFRD's program of extending the frontiers of accelerator science and technology is organized around seeking practical solutions to questions that are critical to the advancement of accelerator-based science. For high-energy physics, the key questions are the following:

What is the farthest energy frontier of accelerator-based HEP?

Extending the energy frontier has been crucial for many of the major discoveries in HEP and we expect that future machines to address the most fundamental questions in particle physics and cosmology will require significantly higher energy than the Large Hadron Collider (LHC) that can be realized through LHC upgrades, design and construction of the International Linear Collider, and other advanced -technology accelerators. The Berkeley Lab program will push the limits of superconducting magnets for very high energy accelerators. In addition, our research in laser plasma acceleration will lead to the application of the very high acceleration fields demonstrated in laser wakefields creating a new class of future machines.

How do we optimize the next generation of colliders?

The next generation of machines will present new technology challenges with increased system complexity and cost. For these machines to be feasible, the designs will have to address and balance a large number of issues to develop an optimum set of parameters at minimum cost, and to achieve the highest possible luminosity. Our program of accelerator simulation will be extended to provide end-to-end models of new machines to support design choices and tradeoffs. These tools, coupled with accelerator costing models, will form a crucial element of future accelerator planning.

How small can we make energy frontier accelerators?

With cost a major factor in planning future facilities, developing new technologies to reduce the size of future machines will be a high priority. Our work on high-field magnets and laser acceleration will contribute to realizing compact accelerators for HEP and other applications.

Can we predict the performance of large accelerators and beam systems?

Predicting the behavior of large accelerators and beam systems will have a major impact on the reliability of new machines and will improve the efficiency and safety of the facilities to be built in the future. Our work in accelerator simulation, especially with end-to-end models, will permit accelerator builders and operators to evaluate the impact of parameter changes before the changes are implemented in the machine. This will reduce time lost and increase scientific output. In addition, our work in beam instrumentation will provide data to validate models.

How tightly can energetic ion beams be compressed in space and time?

The ultimate performance of future machines will be defined by the quality of the beams and by our ability to compress the beam phase-space. Building on experiments by others using high power, relatively long pulse lasers we will explore the feasibility of using high repetition rate compact laser systems to generate and accelerate bright beams of ions. Computer simulations indicate that with suitable solid targets short pulse lasers can produce high-energy ions more efficiently than longer pulse lasers. Using the same experimental approach that we have applied to electron acceleration, we will seek to confirm these predictions and to guide our design of a laser facility dedicated to structured research into the challenges of practical, reliable, laser-driven ion acceleration.

What are the limits of ion source performance in research accelerators?

We will continue to develop ion sources and front-end systems for high intensity accelerators to extend their performance characteristics. We will build on proven capabilities and reputation to deliver high power, high quality ion beams that will be needed to support the forefront science needs of the high energy physics community such as reliable, high power proton drivers.

Current Program: Particle Physics and Cosmology

Probing the Origin of Mass

Exploration of the origin of mass plays a central role in the LBNL physics program. At the present time, the CDF and D0 experiments at the Tevatron form the center of this program through precision measurements of electroweak parameters. In 2007, the ATLAS experiment at the LHC will become one of two premier facilities for such exploration. Further in the future, the International Linear Collider will complement LHC research.

CDF and D0

The Division has a long history of contributions to the hardware, software and physics analysis of these experiments at the Fermilab Tevatron. This program will continue at a decreasing level as groups prepare for physics at the CERN Large Hadron Collider. A major focus will be on top-quark physics. The Tevatron program is being decreased significantly in order to redirect people and funding to the ATLAS program at the LHC. Our plan is to conclude our CDF and D0 activities in FY07.

ATLAS

Berkeley Lab scientists have had a seminal role in understanding the physics signatures at high luminosity hadron colliders. This work began in the 1980's and is continuing now for ATLAS. LBNL has a coordinating role in the development of the ATLAS physics simulation program. This ensures a close tie between the technical aspects of the experiment and the rich physics potential of the LHC.

Berkeley Lab has also been a pioneer in the development of new silicon detector technologies for high-luminosity hadron colliders and has played a pivotal role in the development of pixel detectors suitable for hadron colliders. The software and computing expertise available at Berkeley Lab is now being utilized to lead the development of the framework code (ATHENA) that will provide the backbone of the ATLAS software.

In the next few years, Berkeley Lab scientists will continue to have major roles in the construction of the ATLAS detector and in software for the experiment and will contribute to the commissioning of the detector. In addition, we are taking an increasing role in planning the initial physics program for the experiment based on expertise gained through our work at the Tevatron. It is likely that major physics discoveries will be made very soon after the initial physics run at the LHC and we need to position ourselves to contribute to those. This transition poses a major challenge for the division in that we need to satisfy our commitments to students and postdocs on the Fermilab program and build up our staff for ATLAS commissioning and for physics analysis during a time of significantly reduced funding.

International Linear Collider (ILC)

Berkeley Lab scientists have participated in the development of the community consensus in favor of the ILC over the past few years. We have actively participated in community meetings on the ILC, and brought our expertise to bear where appropriate. We have now initiated an R&D program on silicon detectors and, in addition, we have been active in studies of TPC hardware for application at ILC.

Probing the Matter-Antimatter Asymmetry

The Division is exploring the origin of the matter-antimatter asymmetry in the universe with experiments at colliders and reactors. Studies focus on both the quark and lepton sectors to determine the underlying physics responsible for the asymmetry.

Quark Flavor Physics:

BaBar

LBNL had a crucial role in the BaBar experiment from the original concept through the construction of the detector. At present, we continue to contribute to the BaBar computing strategy and have a major role in physics analysis. That role will continue until 2008 although reduced funding have forced us to decrease the number of postdocs working on the experiment

CDF

In Run II the LBNL initial physics interest is centered on precision measurements of CKM matrix parameters. The main analysis is a measurement of the hadronic moments of semileptonic decays of charged B mesons which provide constraints on QCD corrections to $|V_{cb}|$. This program will continue until 2007.

Lepton Flavor Physics:

KamLAND and θ13

The impressive results from Super Kamiokande on atmospheric neutrinos and from SNO on solar neutrinos were the impetus for new, higher sensitivity measurements of neutrino oscillations. The one-kiloton liquid scintillator KamLAND target/detector with approximately 750 neutrino events per year from power reactors in Japan has confirmed that the Large Mixing Angle solution to the neutrino problem is the correct one. In the future, we will continue to contribute to the KamLAND program through work on the detector and calibration and through a major role in computing and physics analysis. Future upgrades will permit the experiment to study solar neutrinos. At the same time, we will pursue opportunities to study neutrino oscillations at a reactor and to measure the mixing angle θ_{13} at a new site. This measurement is crucial for defining the future of neutrino science in that a large value of θ_{13} would indicate that there are good prospects for the study CP violation in the neutrino sector. This will have a major impact on the physics program at the proposed neutrino SuperBeam. A small group in the Physics Division and Nuclear Science Division is looking at options for the study of neutrinoless double beta decay.

Dark Energy and Dark Matter

The cosmology program within the division uses complementary approaches to study the dark matter and dark energy of the universe. One approach is to use Type Ia supernovae to measure the expansion history of the universe. A second approach uses the Cosmic Microwave Background radiation.

Supernova Cosmology Project and the Nearby Supernova Factory

The LBNL Supernova Cosmology Project was the first group to show that distant supernovae could be discovered on a reliable basis and that their brightness and redshift could be properly interpreted to measure fundamental cosmological parameters. Their data gave the first evidence that the geometry and fate of the universe do not conform to expectations. These astonishing conclusions are the impetus for further studies to reduce systematic errors and to probe more deeply the physics that underlies these phenomena. More low-redshift type Ia supernovae are needed for systematic studies and a broad effort for this is already underway. Even more ambitious is the SNAP proposal to take the supernova search into space.

The Nearby Supernova Factory *(SNfactory*) is designed to lay the foundation for current and next generation experiments to determine the properties of Dark Energy. It will discover and obtain lightcurve spectrophotometry (simultaneous broadband lightcurves *and* spectral time series) for more than 300 SNe Ia supernovae in the low-redshift end of the smooth Hubble flow. Their statistical power alone will lower the statistical error of the current SCP results by up to 50% and will help reduce the systematic error. In the longer term, they will improve *SNAP*'s constraint on Ω_M by 40% and on w_0 by a factor of two.

Dark Energy and SNAP

In order to carry out more precise measurements of the cosmological parameters and determine the equation of state of the dark energy, we have proposed a dedicated satellite-based experiment, the Supernova/Acceleration Probe (SNAP). In November 2003, NASA and DOE announced an agreement to fund a Joint Dark Energy Mission (JDEM) with a competitive process to select a mission in 2006. The SNAP science hinges on the reach to high redshift supernovae and precision weak lensing measurements only achievable in space. Detectors and electronics are likely to be the highest risk area in the mission concept. The visible arrays, and especially the near-IR arrays, are challenging and are a major focus of the Berkeley Lab effort. We are also playing a lead role in the definition of the science program.

The SNAP science hinges on the reach to high redshift supernovae and precision weak lensing measurements only achievable in space. Realization of the science requires state-of-the-art photodetectors in the visible to near infrared (NIR) wavelengths (0.35 – 1.7 μm). A DOE review noted that this is "the most ambitious detector focal plane ever proposed, for ground or space." With the investments we are making in the R&D period, we can advance these devices into the enabling technologies required for the SNAP science program. If we fail to ready these technologies in time the science reach of SNAP will be compromised and its ability to successfully compete for JDEM will be seriously weakened. With a 2m-class telescope and 600-million pixel imager, SNAP can discover and obtain high-signal-to-noise calibrated light-curves and spectra for over 2000 Type Ia supernovae at redshifts between $z = 0.1$ and 1.7. This will help eliminate possible alternative explanations, give experimental measurements of several other cosmological parameters, and put strong constraints on possible cosmological models. The devices we are developing for SNAP will have broad use in the community and will benefit several planned experiments.

Cosmic Microwave Background

A long history of successful measurements of the CMB anisotropies has proved that the CMB is a significant cosmological probe and thus began a program to determine cosmological parameters.

To probe the anisotropies on smaller angular scales we constructed and flew balloon-borne experiments. MAX (Millimeter-wave Anisotropy eXperiment) was followed by an imaging experiment MAXIMA. In 2000 results from MAXIMA demonstrated that the fluctuations had the anticipated structures – acoustic oscillations – on smaller angular scales and provided convincing evidence that the Universe is flat. A first-generation polarization experiment MAXIPOL had a very successful flight in 2003 and data analysis is underway. The CMB is very well understood. Current studies use CMB as a carrier of information about the early universe. Our current emphasis is on the development of new detectors for more precise measurements and on the preparation of next-generation experiments.

Future CMB experiments will probe Dark Energy and the equation of state utilizing the Sunyaev-Zel'dovich (SZ) effect, which modifies the CMB spectrum in a unique way. The APEX-SZ experiment, utilizes the APEX telescope on the Atacama Plateau in Chile. Our collaboration is providing a 300-bolometer array for measurements beginning in early 2005. The next step is the NSF-funded South Pole Telescope (SPT), to be deployed with a 1000 bolometer array at the South Pole in 2007. Another experiment (POLARBEAR) will measure the polarization of the CMB. Inflation predicts the existence of long-wavelength gravitational waves that leave a distinctive imprint on the CMB polarization pattern. The detection of the gravity-wave induced signal would provide what is often considered an irrefutable signature of inflation and probe the energy scale of inflation. The long-term program also includes the Planck Mission to be launched in 2007 and the NASA Inflation Probe (CMBPol) in the next decade.

Theory

The Particle Theory Group, including its LBNL and Berkeley campus components, is one of the world's leading research groups and an important center for the training of students and postdoctoral fellows. The traditional coherence of theoretical research with the experimental program of the Physics Division is a special strength of the LBNL group. Research is carried out in the Theory Group over a very broad range of subjects, ranging from M-theory to phenomenological studies of immediate importance to experiments, especially ATLAS and BaBar.

Particle Data Group

The Particle Data Group provides essential up-to-date summaries of experimental and theoretical particle physics to the HEP community and other physicists and to teachers and students. LBNL is the headquarters of a large international effort to provide compiled and evaluated information on particle properties and related areas, as well as reviews, tables, plots, and formulae.

Advanced Detector R&D

LBNL has a long tradition of advanced detectors for HEP. Many, such as the Time Projection Chamber and the silicon vertex detector, have revolutionized physics at high-energy colliding beam facilities. More recently, the development of fully depleted CCDs for astronomy and large-scale bolometric detectors for the study of the CMB has had a similar impact on cosmology. In recent years decreased funding has forced us to reduce advanced detector R&D but we plan to begin a new effort in detector R&D in FY05.

Computing R&D and support

The goal of this work is to provide computing support for current and future projects. The effort brings together computer science R&D as well as software engineering and systems maintenance. Our computing effort is built on a close collaboration with the National Energy Research Scientific Computing Center (NERSC). NERSC operates a large cluster of computers for production data analysis (PDSF) and also provides computing expertise to many of our experimental programs.

Current Program: Accelerator Physics and Technology

Accelerator Physics

The Center for Beam Physics (CBP) is a cornerstone program of the Accelerator and Fusion Research Division. The Center brings expertise in accelerator theory, accelerator applications of high performance computing, beam electrodynamics and instrumentation, and laser-plasma acceleration that is targeted at the critical needs of the accelerator-based scientific community. Our activities range from support of presently operating accelerator facilities such as the Tevatron and PEP-II to the development of new initiatives and advanced accelerator concepts. We provide leadership for – and make significant contributions to – major High Energy Physics initiatives such as LHC, ILC, and muon accelerators, together with a leading-edge research effort in laser-driven, advanced accelerators and radiation sources. The Center is organized into five main groups: Accelerator Theory, Accelerator Modeling and Advanced Computing, Beam Electrodynamics, Collider Physics, and Lasers, Optical Accelerator Systems Integrated Studies Group (l'OASIS). The advanced simulations work is a part of the DOE's SciDAC program and is tightly coupled to NERSC and its associated expertise in computer science.

Historically, the Center for Beam Physics has been an incubator of new accelerator concepts that support, sustain and enable forefront science. In the future we will work to continue this tradition by maintaining and strengthening those skills that build on our ability to conceptualize, construct, commission and upgrade advanced accelerators. We apply these skills in a manner consistent with support of ongoing and future national needs as defined by the scientific community and the DOE/Office of Science Strategic Plan and Facilities for the Future of Science roadmaps. It should be noted that 60% of the prioritized initiatives in this plan involve accelerator-based science.

We participate extensively in the development of future accelerator facilities that will be needed by the HEP community such as the LHC, the International Linear Collider and the Super Neutrino Beam. Our role is one of providing leadership and making significant contributions to their design, construction and commissioning. In support of near-term HEP objectives, we are part of the US LHC Accelerator Research Program (LARP) in which our involvement is expected to grow over the next few years. In support of mid-term HEP objectives, the Center has developed a leadership role in R&D for damping rings for the International Linear Collider. For the past several years, the Center has had responsibility for design studies of the damping rings for NLC, an effort that has positioned us to assume a leadership role for the accelerator physics, engineering design, construction, and commissioning aspects of the damping rings for the International Linear Collider. At this stage, this work is carried out in the Center's Accelerator Theory Group. In support of far-term HEP objectives, the Center continues its leadership role in R&D for muon colliders. Leadership for this activity is provided in our Collider Physics Group. This work evaluates feasibility of technical approaches that will be needed to build an advanced muon collider to support research in neutrino science. A high-intensity muon storage ring is generally viewed as the ideal source of such neutrinos. LBNL, together with BNL and FNAL, is one of the sponsoring laboratories of the Neutrino Factory and Muon Collider Collaboration, and serves as lead laboratory for this effort.

Collider Science

Tevatron support

To help Fermilab reach their Run II goal 4.4 fb^{-1} by 2009, DOE and Fermilab have requested LBNL's help in improving the luminosity performance of the Tevatron. Our plan is to aid in commissioning of the Recycler Ring, possibly including electron cooling. We are also studying possible instrumentation improvements using expertise of the Beam Electrodynamics Group. Recently we tested a novel real-time longitudinal density monitor on the ALS that could be applied to the Tevatron and, ultimately, to the LHC at CERN to obtain extremely useful knowledge of the longitudinal distribution of stored particles; the intensity and longitudinal shape of all the rf buckets, the fraction of untrapped particles and the population of the abort gap. In the longer term, LBNL looks forward to playing a significant role in accelerator physics at the LHC. Our experience at the Tevatron will be a valuable stepping stone to assist in commissioning the LHC.

Linear Colliders

For the past several years, AFRD has been a leader designing the damping rings for a linear collider; these rings have a pivotal role in providing the stable, low emittance beams critical to achieving high luminosity. Physics limiting the performance of the rings includes coherent synchrotron radiation in the dipoles and nonlinear dynamics in the damping wigglers. Effective coverage of such issues requires a strong core of accelerator physics expertise, closely linked with a number of technical and engineering disciplines, including RF power systems, electromagnet and permanent magnet multipoles and insertion devices, vacuum systems, and controls and diagnostics. Construction of the ILC will provide AFRD a substantial opportunity to develop the engineering design, and to deliver and commission the damping rings.

Neutrino factories

One of the most important discoveries in high-energy physics in recent years is evidence that neutrinos have mass and oscillate into other flavors. A complete study of physics of neutrino oscillations will require an accelerator-based neutrino beam to be directed at a detector thousands of kilometers away. A high-intensity, muon storage ring is the ideal source of such neutrinos. As lead laboratory of the Neutrino Factory & Muon Collider Collaboration, LBNL has embarked on an investigation of the physics and technology issues critical for the development of both neutrino factories based on muon storage rings and muon colliders. We also plan to have a substantial role in the Muon Ionization Cooling Experiment (MICE), which has been approved scientifically by Rutherford Appleton Laboratory (RAL). In the longer term, we hope to participate in the construction and commissioning of a Neutrino Factory accelerator complex, which might be operating in the 2015–2020 time frame.

Laser Acceleration: l'OASIS

Laser interactions in dense plasmas offer the possibility of accelerating particles a thousand times more rapidly that rf-fields in conventional metallic structures. The l'OASIS Program in the Center for Beam Physics is studying how to control fundamental laser-matter interactions to produce reliable high gradient accelerators. In the next decade, we will continue development of

1) an all-optical, laser driven electron accelerator for high energy physics,
2) a high gradient ion accelerator based on laser-solid target interaction as a compact source for isochoric heating of targets for High Energy Density Physics.

A compact ion accelerator is also a potential front-end for conventional ion accelerators that alleviates the need for low phase velocity structures.

Electron acceleration

Our program of electron acceleration consists of a systematic, series of experiments involving the following components:

1. 1 GeV laser module: we recently successfully demonstrated laser propagation over many diffraction distances using preformed plasma channels that serve as optical fibers for guiding the intense, 10 TW laser beams over 2-3 mm to produce 100 MeV electron pulses. By guiding 100 TW class beams over 5-10 cm we expect to produce >1 GeV electron beams.
2. Laser triggered injection: we will explore methods to control the injection timing (and hence energy spread) of electron beams into plasma structures. These methods should produce electron beams with narrow energy spread, exceptionally small emittance and bunch duration <10 fs, containing >10 pC.
3. 10 GeV laser module: By developing techniques of staging several laser driven accelerators together, we expect to achieve energy gains of 10 GeV in a distance less than a few meters.
4. Polarized electron beam source: the HEP-relevance of laser-driven accelerators will be enhanced if a plasma-based polarized electron source can be produced. We will conduct experiments aimed at demonstrating that by carefully (i) populating the proper excited states in hydrogen, (ii) ionizing the gas, and (iii) exciting a plasma wave, we can produce, capture, and accelerate polarized electron bunches.
5. Positron production: another essential element in the development of a laser-based collider will be producing and accelerating positron bunches that are compatible with laser acceleration.

Ion Acceleration

Building on experiments done by others using high power, relatively long pulse lasers we will explore the feasibility of using high repetition rate compact laser systems to generate and accelerate bright beams of ions. Computer simulations indicate that with suitable solid targets short pulse lasers can produce high-energy ions more efficiently than longer pulse lasers. Using the same experimental approach that we have applied to electron acceleration, we will seek to confirm these predictions and to guide our design of a laser facility dedicated to structured research into the challenges of practical, reliable, laser-driven ion acceleration.

After initial experiments aimed at exploring parameter spaces for both the laser and target conditions, we will study the use of intense, picosecond ion beams for isochoric heating of solid targets. The target conditions will be studied with an array of diagnostics including visible to x-ray radiation and particle beams. This line of research will tie into High Energy Density Physics related physics such as opacity measurements for supernovae modeling.

Laser development

Laser-driven accelerators place unique and very challenging requirements on all aspects of the laser development. We must continue to upgrade the performance of the l'OASIS laser system by installing. adaptive optics, active beam stabilizers, contrast measurement and enhancement. In parallel, we will seek support and external collaborators for developing high average power laser systems, including pump lasers. for Ti:sapphire based amplifiers as well as alternative laser materials.

Accelerator Modeling & Advanced Computing (AMAC)

The AMAC group aims to be a world leader in developing terascale accelerator modeling tools and applying those tools to solving the most important and challenging problems in accelerator science and technology. We are engaging this challenge in five ways:

1) developing, in collaboration with other national laboratories and universities, a comprehensive suite of simulations capabilities to model a wide variety of beam dynamics, including space-charge effects, beam-beam effects, wakefield effects, coherent synchrotron radiation effects, and multi-species instabilities;
2) organizing these tools into a comprehensive, coherent, accelerator modeling environment;
3) ensuring that these tools achieve high performance on parallel computing platforms at the terascale, multi-terascale, and (in the future) petascale level;
4) developing end-to-end capabilities for the simulating of complete, complex accelerator systems;
5) moving beyond the paradigm of single-particle design to a new paradigm of accelerator systems design and optimization in the presence of multiple, collective phenomena.

Accelerator Technology: Superconducting Magnets

AFRD's superconducting magnet program consists of a vertically integrated effort to define and advance the cutting edge of superconducting magnet technology for accelerators. The program consists of two major lines of research:

1) innovative design of magnet structures, coil packages, and testing techniques,

2) advancing the performance characteristics of superconducting materials for use in the large-scale production of accelerator magnets

Modern accelerators continue to press the limits of magnet technology. The magnets for the Large Hadron Collider (LHC), soon to be commissioned at CERN, represent the ultimate application of NbTi. Even higher peak fields, field gradients, and beam-induced heat loads will require materials well beyond the capabilities of NbTi. For applications requiring fields >10 Tesla, DOE's superconducting magnet programs is focused on Nb_3Sn, because of its combination of high field performance and commercial availability. While Nb_3Sn was identified as a superconductor over 40 years ago, its brittleness and strain sensitivity kept it from active consideration for use in accelerator magnets until the last decade during which it has been a cornerstone of our program. The newly launched US LHC Accelerator Research Program, much of which is devoted to developing technology for LHC upgrades, adds impetus to our efforts. With the constant drive to extend the energy frontier of HEP, there is a premium for achieving the highest field magnet possible. For this application, Nb_3Sn is the only possible choice.

While we have established the feasibility of Nb_3Sn for accelerators, producing an industrialized, multi-meter length magnet with large aperture and accelerator field quality will require intensive, long-term research. During the next 5 – 7 years we plan to

1) increase the field to the maximum practical limit for Nb_3Sn, ~17 Tesla,
2) increase the bore size,
3) improve the field quality,
4) understand length issues in design and fabrication.

The development of new materials is crucial for the superconducting magnet program. In January 2000 the High Energy Physics office launched a Conductor Development Program (CDP), managed by LBNL, to provide cost-effective, high-performance Nb_3Sn superconductor for the high-field magnets required for the next generation of high-energy physics colliders, as well as upgrades to existing colliders at Fermilab and CERN. In its first two years, the program increased the current density by 50% rapidly reaching its goal of 3 kA/mm^2. Almost immediately, the potential of the new conductor was exploited in HD-1. Two important characteristics still need improvement: 1) the filament diameter must be reduced to ~40 microns to improve stability and minimize magnetization effects, and 2) industrial scale-up to reduce the unit costs. Going beyond 17 T will require a very long-term program to develop economical high temperature superconductors (HTS) in the face of minimal funding and the extreme difficulty in working with these materials.

High-field superconducting magnets will remain a critical enabling technology for future hadron colliders for decades. The requisite R&D program to develop the technology further is well aligned with the traditional strengths of AFRD. Aside from the obvious applications of high field dipoles and quadrupoles in particle accelerators, pushing the limits of materials under the extreme conditions of high field and large forces has benefits for other applications of this technology, such as superconducting insertion devices for light sources and new MRI systems.

Alignment with National and International Priorities

Berkeley Lab scientists have been involved with the efforts to define the future program for the field through contributions to national advisory panels and workshops. Our program is very closely aligned with the national and international priorities. The priorities have been recently affirmed by the Turner Panel Report and Bagger-Barish HEPAP Subpanel Report. Understanding the nature of the dark energy is one of the key science goals identified by the Turner panel of the National Academy of Sciences and by the High Energy Physics Advisory Panel Subcommittee for Long-Range Planning. In addition, panels have endorsed the LHC and International Linear Collider as well as the investigation of the CMB polarization as a probe of the history of the early universe.

An important roadmap for the future HEP program is the DOE Facilities Plan. The ongoing program of the division is very strongly coupled to the currently operating facilities at Fermilab and SLAC and the Large Hadron Collider now under construction at CERN. Beyond the current LHC program and its future upgrades, our HEP program will be based on new facilities outlined in the Facilities Plan.

- Near Term Joint Dark Energy Mission
- Mid-Term International Linear Collider
- Mid-Term Neutrino-less Double Beta Decay Underground
- Far-Term Super Neutrino Beam

Challenges and Needs

In the Physics Division, we have redirected our efforts to ATLAS and SNAP while meeting our short-term commitments to postdocs and students. In FY05 this causes a very significant reduction of efforts in the two Tevatron experiments but will free up funds for ATLAS in the long-term. The commitments to postdocs and students have delayed the ramp up on ATLAS at a time when we need to prepare for detector commissioning and early physics analysis.

Continuity in SNAP funding is extremely important to maintain the collaboration, its forward momentum, and the vitality of the technology programs and to ensure that the SNAP collaboration is able to compete effectively for the Joint Dark Energy Mission. There are many compelling reasons to maintain this ongoing support. Investment in this R&D has been shown to save money in the long run and to greatly improve the likelihood of completing the project on schedule and within budget. Detector development for the SNAP focal plane has been clearly identified as a major technical and schedule risk and it needs continuing funding to make progress. The SNAP collaboration consists of university and national laboratory groups, many of whom have committed institutional funding to leverage the DOE R&D funds. Their continued involvement will have a significant on SNAP and on JDEM. Participation in the science definition process for JDEM will require the use of the extensive simulation capabilities that are being developed.

It is crucial to maintain support for laboratory infrastructure as part of the base funding. At present, there is insufficient funding to permit detector R&D to pursue new ideas that are not directed to a specific project. This puts at risk a long history of Berkeley Lab detector innovation. In addition, the MicroSystems Lab, our chip fabrication laboratory, has only a narrow base of support for CCD work.

Components of our long-term program will require investment in new facilities. The bolometers for our ongoing CMB program have been fabricated using the Berkeley Microfabrication Laboratory (MicroLab) on the UC Berkeley campus, but we have experienced many delays because of equipment problems. Following the model of the Microsystems Laboratory, we are planning to expand our capabilities to include superconducting devices. Although the techniques are similar to silicon processing, materials incompatibilities preclude use of the same equipment. Nevertheless, we can share infrastructure and expertise with the silicon lab. The new facility will be utilized primarily by visitors from university partners, but LBNL must provide technical staff to maintain the facility and provide guidance to external users. We estimate that this facility will require at total of $1100K in equipment and an annual operating budget of $300K.

We will need facilities for our laser-accelerator program. Initially our efforts will use the l'OASIS facility that houses a 10 Hz, 100 TW Ti:sapphire based laser system with up to 6 beam lines, shielded target areas with two target chambers and a remote control room. This facility is unique in the USA. In the second phase, we envision a dedicated facility that can support several external users at the same time and provide laser beam time in a similar fashion to existing "Large Scale European Facilities" such as at the VULCAN laser at Rutherford Appleton Laboratory (UK) and the LULI2000 laser at the Ecole Polytechnique (France). LBNL would be a node in a National Network of such facilities as was proposed in the Science and Application of Ultrafast, Ultraintense Lasers (SAUUL) report.

We believe that there is a need for a modest-size laser facility at Berkeley Lab to serve the national university-based program and to complement our research program at other laboratories. We are not yet sure of the science driver but we plan to explore ways to exploit for particle physics the tremendous progress that has been made at the L'OASIS Facility in generating low energy particle beams accelerated by a laser plasma technique. We will seek to exploit the unique properties of the beam to enable a new class of particle experiments. In the next year, we will undertake a study, including likely university partners, to determine if there is a strong physics case for such a facility at this time. We expect that operating costs for such a new facility would be in the $3M/year range.

The timely analysis of data from the LHC will depend on the reliable operation of the LHC Computing Grid. Within the U.S. the Grid has Tier one centers at Brookhaven (ATLAS) and Fermilab (CMS). Much of the computing for these experiments will be done at Tier 2 centers at university sites. Security for these sites is a crucial issue. Working with computer scientists and security experts at NERSC and Esnet, we have documented serious potential problems with grid security that could disrupt analysis efforts across the collaborations. We are working with Fermilab, SLAC and Brookhaven to organize a workshop to evaluate this threat in more detail and to develop a coordinated response. We expect to prepare a proposal to the funding agencies to address this important issue.

Finally, Berkeley Lab must address some significant demographics issues. To prepare for the future, we need to expand and nurture the next generation of scientific leadership on campus and at the lab. This, of course, will place even greater pressure on our funding.

Strategies for Success

Berkeley Lab will be successful through its individual contributions to the international science and accelerator program and through its role as a leader in major science and technology collaborations with other labs and universities. Both roles are critical for the future of our program. In both respects, Berkeley Lab has a record of unique contributions.