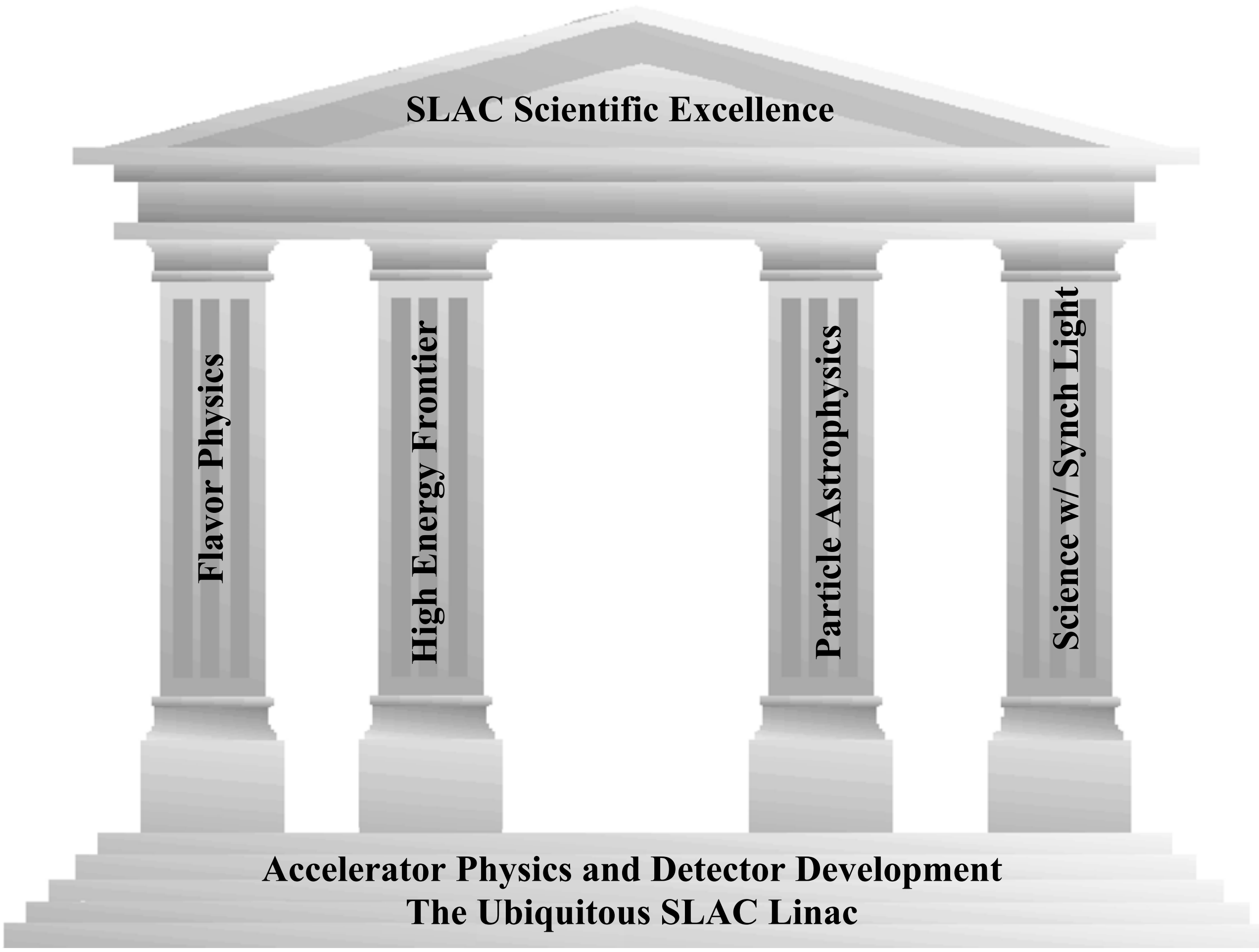
Report of the SLAC Scenarios Study

2/23/04



Report of the SLAC Scenarios Study 1
Executive Summary 3
1 Introduction 6
2 Process 6
3 Pillars of the SLAC Program 7
3.1 The High Energy Frontier 7
3.1.1 Models for SLAC Participation in Linear Collider 8
3.1.2 Models for SLAC Participation in LHC/LHC Upgrades 11
3.1.3 High Gradient Accelerator R&D 12
3.1.4 Dreams Deferred at the High Energy Frontier 12
3.2 Flavor Physics 14
3.2.1 The B Meson System 14
3.2.2 Neutrino Physics 15
3.2.3 Flavor Physics: Dreams deferred 16
3.3 Science with Synchrotron Light 16
3.4 Particle Astrophysics and Cosmology 17
4 Scenarios 18
5 Conclusions 19
Appendix A - 21
Appendix B - 22
Appendix C - 23

Executive Summary

In January, 2003, the Director of SLAC requested a study of scenarios for SLAC's long term future with a focus on what the laboratory will look like in 2015. The context in which the study was to be carried out was specified to be:

- There will be a linear collider built and SLAC will be a major participant.
- The PEP-II/BaBar program has a clear future to 2010.
- The future of SSRL to 2015 and beyond is determined by SPEAR 3 and LCLS.
- There will be growth in particle astrophysics at SLAC with the initiation of KIPAC (Kavli Institute for Particle Astrophysics and Cosmology).

The committee was asked to explore two independent aspects of SLAC's future:

- Developing models for SLAC's role in a future linear collider.
- Exploring other exciting science opportunities for the laboratory to be engaged with in the linear collider/LCLS era.

The scenarios study was inclusive of SLAC staff and users in consideration of potential HEP components of the program. The scenarios committee did not seek to extensively assess and review the core scientific elements of the synchrotron program. The opportunities for synchrotron science on the SLAC site have been aggressively developed in the past 5 years. There are clear general trends and these are adequate and relevant for the purposes of the study. These include an anticipated doubling of the staff supported by SSRL by the year 2010, after which the SSRL staffing levels will remain roughly constant.

In the process of developing models for SLAC's role in a future linear collider, the committee reached a significant conclusion:

- The committee studied what the component pieces of SLAC's commitment to a linear collider might be, and how the laboratory's effort would change depending on the technology choice for the RF power and accelerating structures, management models and location decisions for the linear collider. The committee came to the conclusion that the scope of SLAC's on-site effort in supporting the linear collider is largely independent of where the linear collider is located and what technology is chosen. The details of the involvement will change with these downstream decisions, but the scenarios were remarkably stable with respect to the linear collider options. The committee wishes to stress that the conclusions of the scenarios study in no way suggest that the laboratory should diminish its commitment to the warm x-band RF technology and additionally, the committee recognizes that choice of a US site for the linear collider would enormously benefit the entire US HEP community.

Four scenarios were developed for the future of the laboratory. In developing scenarios for the future of SLAC, the invariance of the scale of SLAC's linear collider effort simplified things greatly. The driving program elements that shape the future of SLAC are:

- The involvement with the linear collider

- The future of the B-factory program
- The SSRL (synchrotron light) program
- Particle astrophysics and cosmology
- The program of advanced accelerator R&D

Smaller efforts that were considered as attractive science opportunities for SLAC to be involved in were a future experiment to measure the Majorana mass of the neutrino in neutrinoless double beta decay and potential participation in the luminosity upgrades to the LHC. While potentially very important to the scientific program of the laboratory, the scale of these efforts was small and therefore they will not be defining programs for the evolution of the future of the laboratory. We have deliberately not included them in the description of the scenarios considered for this reason.

Four scenarios were evaluated in detail. The driving program elements that shaped those scenarios were:

- Scenario I
  - Major participation in a linear collider whether it be US or non-US sited
  - SPEAR3, LCLS as planned
  - No B-factory upgrades past 3 x 10^{34} $cm^{-2}s^{-1}$; B-factory turns off in 2010
  - Full linac capability preserved
  - Particle astrophysics and cosmology doubling in 10 years
  - Advanced accelerator R&D doubling in 10 years
- Scenario II
  - Major participation in a linear collider whether it be US or non-US sited
  - SPEAR3, LCLS as planned
  - B-factory upgrades to 2 x 10^{35} $cm^{-2}s^{-1}$ in 2010 with continued running past 2015
  - Particle astrophysics and cosmology doubling in 10 years
  - Advanced accelerator R&D grows by 50%
- Scenario III
  - Linear collider sited in the US
  - SPEAR3, LCLS as planned
  - B factory at SLAC turns off in 2010; SLAC participates in a B-factory upgrade to 10^{35} - 10^{36} $cm^{-2}s^{-1}$at KEK with continued running past 2015
  - Full linac capability preserved
  - Particle astrophysics and cosmology doubling in 10 years
  - Advanced accelerator R&D doubling in 10 years
- Scenario IV
  - Linear collider sited outside US
  - SPEAR3, LCLS as planned
  - SLAC B-factory upgrades to 10^{36} $cm^{-2}s^{-1}$ in 2010 with continued running past 2015
  - Particle astrophysics and cosmology doubling in 10 years
  - Advanced accelerator R&D grows by 50%

In all scenarios the laboratory grows over the next decade. On the assumption that the linear collider construction is essentially complete by 2015, Scenario I results in 20% net growth in laboratory staff by 2015, dominated by the growth in the area of synchrotron radiation while Scenario IV results in 30% net growth in laboratory staff by 2015.

The committee would like to stress that this attempt to lay out scenarios for the long term future of SLAC is being done at a time when the world high energy physics community is unified in supporting a high energy high luminosity e+e- linear collider as the highest priority next project for the field. However the timeline for the machine, its technology, and its location are all unknown. While the scenarios described are remarkably robust against decisions of location and technology for the linear collider, the high energy physics part of the program is not robust with respect to major changes in the timeline for construction of the machine. As the schedule for the linear collider becomes clearer in the next few years, we believe it would be appropriate to revisit the HEP elements of the scenarios and update them as necessary.

The committee deliberately avoided the question of 'What if there is no linear collider'. It was not in the charge. The committee felt strongly that 'no linear collider' is an issue for the field as a whole and it threatens the survival of a healthy US HEP program. It is not foremost an institutional issue for SLAC. In fact the imperative would be to address the issue for the field first and SLAC would be prepared to help the community in that unfortunate situation. The steps taken in this study would inform that process.

Finally the scenarios committee was aware that in two of the four scenarios there is no frontier onsite high energy physics facility operating at the laboratory in 2015. The program is rich enough and the laboratory strong enough to be successful and to thrive in that situation. The committee noted that even without a forefront high energy physics facility on site, the linac will continue to be an essential part of the program. The linac is an important feature for possible upgrades to the LCLS, R&D for the linear collider and linear collider detector, and advanced accelerator R&D studies. The ubiquitous SLAC linac has enabled forefront science for 40 years on the SLAC site and is likely to do so for decades to come.

1 Introduction

In January, 2003, the Director of SLAC requested a study of scenarios for SLAC's long term future with a focus on what the laboratory will look like in 2015. The context in which the study was to be carried out was specified to be:

- There will be a linear collider built and SLAC will be a major participant.
- The PEP-II/BaBar program has a clear future to 2010.
- The future of SSRL to 2015 and beyond is determined by SPEAR 3 and LCLS.
- There will be growth in particle astrophysics at SLAC with the initiation of KIPAC (Kavli Institute for Particle Astrophysics and Cosmology).

The charge to the committee and the committee membership are given in Appendix A and B. In carrying out the study the committee adhered to several guiding principles:

- The laboratory must be engaged in cutting edge science and developing the tools that enable that science.
- A primary mission of the laboratory is to serve the user community.

The focus of the study was on the major program elements of the laboratory. Smaller R&D efforts, essential to the field and the laboratory, are not discussed in detail.

2 Process

The committee divided into two subgroups to explore two independent aspects of SLAC's future:

- Developing models for SLAC's role in a future linear collider.
- Exploring other exciting science opportunities for the laboratory to be engaged with in the linear collider/LCLS era.

In the first phase of the study, the two subgroups acted independently but with subgroup leaders meeting regularly. The subgroups then came together to ask what SLAC looks like in 2015 in various scenarios. Scenarios were developed based on physics opportunities, with explicit models of lab manpower and budget.

The scenarios study was inclusive of SLAC staff and users in consideration of the HEP components aspects of the program. Appendix C gives a list of the public talks and day long workshops that were part of the information gathering phase. The committee website at http://www-project.slac.stanford.edu/lc/local/scenario/ provides links to all of the talks and documents, including a series of white papers drafted by members of the committee, that helped inform the scenarios process.

3 Pillars of the SLAC Program

The future SLAC scientific program will rest on the foundation of technical expertise in innovating, building and designing frontier accelerators, in inventing and developing new detector technologies, instruments and methodologies, in the experience at the laboratory in managing large scale projects, and in the ubiquitous SLAC linac, which has enabled forefront science for 40 years and has the potential to continue in that role for decades to come. In designing scenarios for the future lab program, the committee organized its thinking around the areas of scientific exploration in which the lab would be engaged. We defined four scientific areas that we believe the lab should be contributing to and we refer to these as the 'pillars' of the SLAC program:

1. The High Energy Frontier
2. Flavor Physics
3. Science with Synchrotron Light
4. Particle Astrophysics and Cosmology

To ensure a healthy and vital future for the laboratory, the scientific investigations in all of these areas should be at the scientific frontiers. All four pillars must be strong for the laboratory to optimally serve our user community and have its most vital future.

In selecting the scientific opportunities that could be represented in the future of the High Energy Component of the SLAC program, the criteria the committee used were:

- Cutting edge science opportunities as determined by the HEP community.
- Opportunities to engage and serve the user community.
- The scope of SLAC's contributions to an effort must be commensurate with SLAC's role as a national laboratory.
- A linear collider exists somewhere in the world and therefore projects that would duplicate the capabilities of the linear collider are not appropriate to pursue. The existence of the linear collider provides constraints on the overall resources available to the program that should be respected.

3.1 The High Energy Frontier

For the long term health and vitality of the field, it is important that SLAC play a leadership role in experiments at the high energy frontier. The committee considered the linear collider to be the highest priority for the high energy program at the laboratory, and the focus of the laboratory's future energy frontier program. SLAC has invested heavily in and continues to champion the warm x-band RF technology choice for the main linacs, and we strongly support a US site for the facility. However, the laboratory is committed to the linear collider independent of location and independent of technology. The committee studied what the component pieces of that commitment might be, and how the laboratory's on-site effort would change depending on the technology choice for the RF power and accelerating structures, management models and location decisions for the linear collider. The committee came to the conclusion that the scope of SLAC's on-site effort in supporting the linear collider is largely independent of where the linear collider is located and what technology is chosen. The details of the involvement will change with these downstream decisions, but the scenarios were remarkably stable with respect to the linear collider options. SLAC involvement in *operation* of the linear collider accelerator, however, could take a range of forms and scales. Considerations of technology, geography and the operations-phase management of the linear collider would influence the form of SLAC's participation at this stage. There will be significant participation in detector operations and physics in all cases.

The linear collider will be SLAC's primary engagement with the high energy frontier. However the LHC will open the high energy frontier 5-10 years before the linear collider is operational. The scenarios committee recommends that the laboratory consider participating in the luminosity upgrade program at the LHC to provide opportunities to the laboratory and user community to engage with the high energy frontier in advance of the turn on of the linear collider. There are unsolved machine and detector issues with the luminosity upgrade to which SLAC, with a modest program, could make unique contributions. The committee acknowledges that SLAC investment in the LHC luminosity upgrades would have to be controlled carefully so as not to divert resources and focus from the laboratory's traditional role in electron-based accelerators in general and the linear collider specifically. However the physics opportunity of the LHC is sufficiently exciting that this option merits consideration.

Finally, the long-term future of high energy physics will depend on a continued program of aggressive accelerator R&D aimed at making future machines both feasible and affordable. It is imperative for the health of the field that SLAC continue and even expand its efforts in Advanced Accelerator R&D.

3.1.1 Models for SLAC Participation in Linear Collider

The assumptions for the development of SLAC participation in the linear collider were as follows:

- The costing details were based on the 1999 NLC Lehman cost model
- The time line of the project was assumed to be:
    - R&D, design and engineering through 2008
    - Construction from 2009 through 2015
    - Operation after 2015
- The funding model was assumed to be:
    - 25% US contribution to TPC (Total Project Cost)
    - 35% premium (additional) for the right to host
- A central project office was assumed which manages the conventional construction and technical system installation
- The operations phase of the linear collider was beyond the time horizon of the scenarios study

Management Models

In order to develop a realistic model of SLAC participation in a linear collider, a model for the management of the project was constructed. It was assumed that a central project office (CPO) would be formed at the start of construction and that the CPO would manage approximately 40% of the TPC. In the model used, the CPO would be responsible for approximately 80% of the civil construction with the remainder offset through equipment contributions. The CPO would be responsible for the technical system installation, 50% of the OPC (Other Project Costs) covering 2/3 of start up and pre-operations costs, and 40% of the management and support costs of the project. It is inevitable that some SLAC staff would leave the laboratory (if not permanently, then for many years) to join the CPO. These staff and the work they would perform would no longer be counted in the "SLAC level of effort" discussed henceforth. It is likely that the size of the drain on the laboratory will depend significantly on the proximity of the site to SLAC and less so on the choice of RF technology.

Two versions of the project management were considered. A primary laboratory model was considered where the primary lab would sub-contract major portions of construction to the participating laboratories. The second model was a collaboration model with strong central management where the collaborators provide in-kind and cash contributions. The second model was judged to be a better model for SLAC participation but it was also recognized that the choice of model resulted in only small differences in terms of contributions during construction. Commissioning responsibilities are likely to be smaller in the primary laboratory model because the laboratory would assume control earlier, and the greatest differences were believed to come in the area of operational responsibility.

Cost Model

The cost model for the linear collider was developed assuming a 500 GeV collider that could be upgraded to 1 TeV, with two interaction regions. Considerable cost details were needed to form a model of how the construction of the collider might be divided. For this reason, the normal conducting collider cost model was based on the NLC 1999 Lehman cost model using information at WBS levels 5 and 6 with updates for Engineering, Design, Inspection and Administration. The total cost of the NLC 1999 Lehman estimate was $5.1B without contingency or escalation. The present estimates of the NLC costs differ from the 1999 values but not enormously.

Similar levels of detailed information were not available for a superconducting collider. To develop a cost model, the NLC 1999 Lehman costs were scaled such that the cost ratios of the M&S portions of the global subsystems such as linac rf or damping rings were the same as in the TESLA TDR released in 2001. For this exercise, the total cost of the superconducting linear collider was assumed to be the same as that for the normal conducting linear collider. This total cost is similar to the estimate developed in the study of the TESLA costing methodology lead by Fermilab and published in 2002.

To divide the collider for construction, the costs were separated into collider global costs and technical costs. For the normal conducting collider, the global costs were divided into civil construction ($1.7B) and OPC ($0.3B), controls ($0.3B), manufacturing ($0.3B) and management($0.3B) with similar values for the superconducting machine. The technical costs were $2.2B, and a cost matrix was developed separating the costs by area (injector, main linac, beam delivery system) and technical subsystem (low level RF modulators, klystrons, structures, distribution, magnets, vacuum, instrumentation and installation.) The technical system installation costs were assigned to the project office. The R&D costs were assigned to the respective areas.

Role for SLAC in Linear Collider

SLAC aspires to have a major role in the linear collider. This would include a leadership role in the design effort, and primary efforts in accelerator physics (such as beam line design, modeling and commissioning), high power RF systems and the polarized electron source. The lab would also engage in developing technologies that might be useful such as s-band and l-band RF sources and structures. In the process of developing a specific model of what SLAC might contribute to the construction of the linear collider, it was determined that a reasonable target for the level of SLAC responsibility, occurring at SLAC, was roughly 10% of the TPC. As other models were explored it was found that this target level of responsibility was reasonable whether the linear collider was onshore or offshore and independent of the technology chosen.

The specific cost model for the US contribution was:

- Onshore: U.S. contribution is 60% of TPC; SLAC is responsible for ~10% of TPC
- Offshore: U.S. contribution is 25% of TPC; SLAC is responsible for ~10% of TPC.

To set the scale, a 10% of the TPC contribution on-site at SLAC corresponds to roughly $800M over ~ 8 years when contingency and escalation are taken into account.

In developing a model for the scenarios study, the committee focused on specific areas for SLAC involvement with full realization that in final negotiations the hopes and aspirations of many other players will be involved and must be respected. This study in no way attempts to lay claim to any particular aspects of the linear collider development for the laboratory.

A matrix of the project was developed, assigning responsibility for areas and different technical systems to different parties. In detailed studies it was found that the linear collider project could be broken into numerous pieces that would suit the laboratory's interests. The general philosophy adopted in developing models of participation was to:

- Look for topics with large accelerator physics contribution
- Look for early contributions to ease the transition from the design stage
- Look for early commissioning to get established on the project quickly

As an example, in a warm x-band RF technology, onshore model, SLAC might assume responsibility for:

- A major role in the design effort (2-3% of the TPC, depending on test facilities)
- The injector subsystem including damping rings (3% of the TPC)
- The s-band power and structures (2% of the TPC)
- 50% of x-band klystrons and x-band structures (3% of the TPC)

An alternate option would be to include responsibility for the beam delivery system, which is a good match to detector work; however, the slower construction schedule and the late commissioning makes that option less attractive.

While the basic rf technologies in a cold linear collider are not as good a match to the SLAC expertise, it is still possible to make a significant contribution (~10% TPC) that is well aligned with the laboratory's strengths and future directions. For example, playing a leading role in the design effort and taking responsibility for the injector system represent a significant and important contribution, much as they do in the warm technology case. Development of the 1.3 GHz klystrons and/or the beam line instrumentation might also be logical contributions from SLAC to the LC project. Responsibility for other technologies such as the magnet or vacuum systems, which may not be as well matched to the laboratory, could also be undertaken.

The overall laboratory effort would peak with approximately 250 technical personnel (physicists, engineers and technicians) working on the project; the peak level of effort is similar to that needed to construct the SLAC B-factory however the duration of the construction project would be much longer than the B-factory. The effort peaks early in the project and tapers off in the operating phase to roughly 100 technical people.

SLAC Role on Linear Collider Detector

SLAC would like to have major responsibility for one of the two linear collider detectors. A collaborative construction model was assumed. Approximately 50% of the work on the detector would be managed through SLAC with roughly 100 SLAC physicists and engineers on the project. In this model SLAC would do some prototyping and assume responsibility for major assembly of the detector.

It was recognized that it would be very desirable for SLAC to be a detector collaboration host. It was felt this goal might be achievable for a California site or an offshore site, but was an unlikely outcome if an Illinois site was chosen. It was also recognized that the SLAC linac provides unique test beams for the R&D phase of the linear collider detector development.

3.1.2 Models for Potential SLAC Participation in LHC/LHC Upgrades

The LHC will provide a wide range of physics at the energy frontier before the linear collider begins operation. There is strong scientific motivation for SLAC to engage in this physics. To join the LHC at the present stage, the most likely path could be to take on some significant responsibility in the accelerator and detector upgrades for the LHC.

LHC upgrade options have been described in the Ruggiero report and are planned to occur in three phases: Phase 0 takes place starting with turn-on in 2007, and involves pushing the installed hardware to its limits. Phase 1 (~2012) is a luminosity-only upgrade. Phase 2 (2020?) is an energy-and-luminosity upgrade. The best avenue for SLAC involvement would likely be through the Phase 1 detector and machine upgrades.

LHC Detector Upgrades

The R<20cm inner tracker in the luminosity-upgraded LHC requires a new detector technology to cope with the high radiation environment and tracking requirements. R&D for this device is an attractive project for a possible new initiative from the SLAC community. Because present LHC collaborators are occupied heavily with completing the first-phase detectors, new groups are needed to carry out the challenging R&D. The SLAC community has extensive experience in silicon detectors, and SLAC could potentially play the role of an R&D host and detector fabrication center in collaboration with Santa Cruz and LBNL who are already heavily involved.

Significant involvement in such a major upgrade project will be a necessary step to allow SLAC access to the rich LHC physics opportunities. Considering the role of the LHC as the premier energy frontier facility for the next decade, the scientific benefit of this effort is quite clear. Involvement with LHC physics is particularly beneficial in the scenario in which there is no major on site facility in the post-PEP-II era, leaving a 'physics gap', before the start of the linear collider physics program.

LHC Machine Upgrades

The Phase 1 LHC luminosity upgrade (~2012) involves, among several other changes, substantial RF system additions to produce shorter bunches. The Phase 2 (2020?) energy-and-luminosity upgrade involves accelerator-complex wide upgrades, and rests critically on the successful completion of Nb_3Sn R&D programs to produce higher-field superconducting dipoles.

Three major system upgrades have been proposed as candidates for SLAC participation: (1) the RF systems upgrades in Phase 1 for bunch length alteration, (2) the RF crab cavities near the interaction points for increased crossing angle in Phase 1 and (3) the superconducting accelerator for the H-minus source upgrade and Proton Synchrotron Booster replacement in Phase 2. The RF crab cavities were considered as a goal of a possible new SLAC effort in superconductivity R&D. The scenarios committee used the first two as models for participation in the luminosity upgrade.

3.1.3 High Gradient Accelerator R&D

The long range future of particle physics will require pushing the energy frontier beyond the LHC and the linear collider. New ideas coming from advanced accelerator R&D are essential for future facilities that are both feasible and affordable. Advanced accelerator concepts cover a range of physics and engineering well beyond traditional accelerator physics, and it is critically important to engage a broader spectrum of scientists and engineers in advanced accelerator research. Specialized experimental facilities based on the SLAC accelerators are being developed and will be made available to a user community. These facilities will include a multiple-beamline facility supplying high quality, well-diagnosed electron beams of up to 350 MeV, and a high-energy beam test facility supplying GeV-class beams for accelerator test experiments. Well controlled, versatile beam properties, excellent diagnostics, and a shared base of knowledge in performing experiments at these facilities will enable users to rapidly execute experiments on the most promising advanced acceleration techniques. Some of the proposed proof-of-principle experiments include:

- Beam-driven plasma wakefield acceleration – energy is transferred from a leading electron bunch to a trailing bunch via density waves in a high-density plasma
- Laser-driven dielectric structures – energy is coupled from the most efficient lasers to electron beams using dielectric structures fabricated by semiconductor lithography or fiber drawing processes

Future experiments may include:

- Laser-driven plasma wakefields – high power laser pulses directly excite density waves in a plasma, transferring energy to an electron bunch
- Two-beam accelerator structure development – energy is transferred from one electron bunch to another via wakefields left behind in microwave structures

Further, these user facilities will combine very high energy density electron beams and lasers, opening other possibilities for inquiry into high energy density physics or laboratory astrophysics.

The scenarios study concluded that the level of effort in this area should grow with a continuing emphasis on engaging the intellectual resources of the user community in what is the most challenging problem for the future of the field. The accelerators at SLAC will continue to be invaluable tools in the pursuit of this science.

3.1.4 Dreams Deferred at the High Energy Frontier

A variety of other options for machines that would be on the SLAC site and address science opportunities at the high energy frontier were discussed in the scenarios process. Among the opportunities considered were:

- An e^+e^- -> ZH factory, based on two-beam acceleration and producing ~10,000 Higgs bosons per year, was discussed for the SLAC site for an estimated cost of $3B. This option was eliminated because it duplicates the capabilities of the linear collider.
- A two-beam-based Z factory producing ~6 x 10^9 Z bosons per year was discussed for the SLAC site for an estimated cost of $1.5B. This option was eliminated because it was viewed as too expensive for precision electroweak physics in the linear collider era.
- A gamma-gamma collider capable of producing ~2000 Higgs bosons per year was discussed for the SLAC site for an estimated cost of $1B. While it was recognized that this opportunity offered unique access to the $H\gamma\gamma$ coupling, it did not offer a broad physics program. It also depends on the Higgs to be relatively light to be practical.
- It was suggested to use a plasma afterburner on the SLC to produce ~1000 Higgs bosons per year via e^+e^- -> ZH. The technology is too immature for this option to be considered at this time.
- A 50 million Z per year factory was discussed on the SLAC site using a multi-bunch, mostly s-band linac for a relatively modest cost. Such a facility could substantially reduce the uncertainties in precision electroweak observables, particularly A_{LR} and A_b. Depending on the model of new physics, these improved measurements could provide important information, even in the LHC era. In principle, parts of the accelerator could serve as a linear collider test bed. Ultimately it was recognized that the price-tag being

quoted by the proponents was unrealistically low when one considered the impact of the LCLS which by then would already be installed in the linac tunnel. It was also realized that the timescale did not match serving as a linear collider testbed.

Most of these options were eliminated because of their conflict with the linear collider. Should the linear collider be significantly delayed or cancelled, we feel that some of these options would be worth revisiting.

3.2 Flavor Physics

The phenomenology of quark and lepton mixing provides a window on the high energy frontier in a unique way. The current focus of quark mixing is to understand the phenomenology of CP violation and to search for physics beyond the standard model by probing rare processes that are suppressed in the standard model. In the era of the LHC, we will want to see the footprint of the new physics discovered there in the pattern of mixing parameters and CP violating asymmetries in the flavor sector. The tiny mass of the neutrino is potentially related to the unification scale. Both the quark and neutrino sectors may hold clues to the origin of the matter-antimatter asymmetry in the early universe. The scenarios committee saw exciting opportunities in flavor physics that the laboratory should consider pursuing.

The committee concluded that several scenarios for the future of B-physics on site should be explored, ranging from ending the B-factory program in 2010, to an aggressive program to upgrade the facility to a super-B factory with a peak luminosity of more than a factor of 100 greater than is currently achieved. The committee also felt that the science goal of measuring the lepton-number-violating Majorana mass of the electron neutrino should be pursued if the EXO R&D project is successful.

3.2.1 The B Meson System

The excellent performance of the present e^+e^- B factories in establishing CP violation in the B system, and probing flavor physics more generally, provides strong motivation to consider much higher luminosity machines. Although precise measurements using the "golden mode," B -> $J/\psi K_s$, and related modes, are in good agreement with the Standard Model, other modes requiring larger data samples may be more sensitive to new physics. There is a 2.6σ hint of a deviation from the Standard Model in one of these modes, B -> ϕK_s. Quark flavor physics in general provides a sensitive avenue to many types of physics beyond the Standard Model. New physics in CP violation may also shed light on the cosmic baryon asymmetry, which cannot be explained within the Standard Model.

If a very high luminosity e^+e^- B factory is built, it will operate in the LHC era. The LHC should be able to directly discover new physics associated with electroweak symmetry breaking, and determine its mass scale. However, a very high luminosity e^+e^- B factory would supply unique and complementary flavor and CP information. For example, in supersymmetric models, the LHC can measure flavor-diagonal squark masses, whereas B physics experiments are sensitive to flavor-off-diagonal squark mass terms and CP-violating phases.

The design luminosity of the PEP-II collider was 3×10^{33} cm^{-2} s^{-1} and the machine is routinely running at more than twice that value. In the near term, between now and 2006, there are plans to upgrade PEP-II to reach a luminosity approaching 3 x 10^{34} cm^{-2} s^{-1} by installing additional RF stations and an improved interaction region. The scenarios committee considered the physics opportunities and the technical challenges for either of two significantly higher luminosity options, 2 x 10^{35} $cm^{-2}s^{-1}$ and 10^{36} $cm^{-2}s^{-1}$, corresponding to 2 ab^{-1} and 10 ab^{-1} per year.

Such a machine might begin operation between 2008 to 2011. The 2 x 10^{35} option could be constructed in the PEP tunnel, retaining the PEP-II RF frequency and one of the two vacuum systems. The 10^{36} option could also be constructed in the PEP tunnel, but would require a new RF system (driven by the need to change the frequency) and new vacuum systems for both rings. Obviously more luminosity is preferable to less luminosity, if all other variables are equal. Higher luminosity will afford the necessary statistical precision to quantify the degree of new physics effects in CP violating asymmetries in modes such as B -> ϕK_S, B->$\rho\rho$, and B->$\pi\pi$, as well as in the kinematic distributions associated with B-> sl^+l^-; in addition it will allow the observation of rare decays with neutrino final states such as B-> $\tau\nu$, and B->$s\nu\nu$. This program is complementary to that of hadron B physics facilities.

The 10^{36} machine will be more costly, challenging, and time-consuming to construct, factors that are likely to be relevant if SLAC is simultaneously playing a key role in the construction of a linear collider. The detector for a 2 x 10^{35} machine is also somewhat simpler; many elements of the present BaBar detector may survive at this luminosity, whereas more components would have to be replaced for a 10^{36} machine. For these reasons, it is worthwhile to keep both options on the table for the time being.

The scenarios committee concluded that if there is new physics in the flavor sector, upgrades to the B-factory should be pursued. In light of the physics uncertainties we considered the following four options:

- No B-factory upgrades past current 2006 goal of 3 x 10^{34} cm^{-2} s^{-1}
- Upgrade to 2 x 10^{35} cm^{-2} s^{-1}
- Upgrade to 10^{35} - 10^{36} cm^{-2} s^{-1} at KEK with SLAC participation
- Upgrade to 10^{36} cm^{-2} s^{-1} at SLAC

Which of these options to pursue is the major variable between the future scenarios we considered. To make these upgrade plans a reality, and to support the current B-factory program, SLAC must invest in accelerator R&D aimed at addressing the technical challenges of the luminosity frontier.

3.2.2 Neutrino Physics

Members of the SLAC community and the Stanford Physics Department are currently involved in a neutrinoless double-beta-decay R&D program (EXO) that, if successful, will lead to a proposal for a full scale experiment. The Scenarios Committee considered possible new projects for SLAC involvement in neutrino physics, as well as more extensive involvement in neutrinoless-double-beta-decay experiments.

The committee felt that neutrinoless double-beta-decay experiments are preferred because they are almost unique in possibly addressing the questions of lepton-number violation, neutrino type

(Dirac or Majorana), and absolute mass scale. The committee developed a scenario based on EXO proceeding to full development. SLAC should consider other technologies if the development of the liquid-xenon approach of EXO reaches a show-stopper.

There are other very interesting questions in the neutrino sector being addressed by a variety of technical approaches. While the scenarios committee did not recommend active participation in them, it would be good for the SLAC community to participate at an appropriate level in neutrino study groups being organized by the particle physics community. Significant work is going on nationally and internationally to understand the sensitivity of possible future neutrino experiments. New theoretical and experimental issues are being raised and explored. In order to have an informed opinion on the most promising directions for the future, representatives of the SLAC community should participate in the ongoing studies.

3.2.3 Flavor Physics: Dreams deferred

A variety of other options were proposed during the study for facilities, both on the SLAC site and distant from it, which address science opportunities in flavor physics. Among the opportunities considered were:

- A $\gamma\gamma$ collider at 30 GeV to do QCD studies was discussed for the SLAC site. It was felt the HEP interest in the program was weak.
- It was suggested that the SLAC community participate in long-baseline neutrino oscillation experiments. However, many others are working on this problem and there is not a clear SLAC role.
- During the scenarios study there was discussion about using reactor neutrinos to measure θ_{e3} in advance of any other technologies. An early measurement of θ_{e3} or a limit on it would be invaluable input for the planning of future experiments. Whether the SLAC community could make a unique contribution to future reactor experiments would require further investigation. Initial estimates on the size of this effort left it 'below the radar' for the scenarios study process.

3.3 Science with Synchrotron Light

The science opportunities enabled by synchrotron light have brightened in the past decade. While the Scenarios Committee did not seek to extensively assess and review the core scientific elements of the synchrotron program, there are clear general trends and these are adequate and relevant for the purposes of the study. The opportunities for synchrotron science on the SLAC site have been aggressively developed in the past 5 years, and this 'pillar' of the program is very strong. SPEAR has just been upgraded to SPEAR3, making it the equal of any third generation source in its energy range in the world. SPEAR3 will continue to serve a broad user community investigating a broad range of science that can be accessed with synchrotron light, including materials science, x-ray crystallography and environmental science. The major new initiative in this area is the Linac Coherent Light Source, LCLS, an x-ray FEL that will use the final 1/3 of the SLAC linac to make an intense coherent beam of very short pulse angstrom photons. The LCLS is a tool that will open new frontiers in the fields of femtochemistry, atomic physics, in the study of the nanoscale dynamics of condensed matter, and in studies of plasmas and warm dense matter. A coherent light source in the hard x-ray region was identified by the synchrotron light community as having the most exciting potential for innovative science in these areas.

The path forward for both of these facilities is well determined. Within the timescale of the Scenarios Study, there will be plans developed for the upgrades of the LCLS, including the construction of additional undulator beamlines and experimental stations. These upgrades may extend to using the entire length of the linac structure.

High performance lasers will be an integral part of the LCLS infrastructure. The photo injector laser, laser-based beam diagnostics, and lasers supporting the LCLS experiment program will become essential parts of SLAC operations. A likely consequence is that laser engineering and R&D will become a core competency of SLAC, and a visible element of the SLAC organization.

An important part of the synchrotron light program will be the continued accelerator R&D aimed at future synchrotron facilities including the LCLS upgrades. Electron gun R&D is important to LCLS and every FEL. Undulator R&D must pace the progress in gun performance. There have been and will continue to be very competitive efforts in these areas, at SLAC and elsewhere in the world. The high-energy linac beam at SLAC is, however, unique in the US, and in the world as well for some time to come. Experimental research in collective effects during bunch compression of high-energy beams cannot be carried out elsewhere.

3.4 Particle Astrophysics and Cosmology

A decade ago the HEP program at SLAC began to include the closely connected field of particle astrophysics and cosmology. The current focus of the program is the construction of the Large Area Telescope for the GLAST mission: a joint DOE/NASA project that will map the gamma ray sky with a precision in energy and angular resolution never before achieved. The future of the particle astrophysics program at SLAC beyond GLAST will be strongly influenced by the Kavli Institute for Particle Astrophysics and Cosmology, a joint initiative with the Physics and Applied Physics Departments on campus. This is clearly a growth area for the laboratory for the next decade. It is anticipated that the particle astrophysics effort at SLAC will at least double over the next ten years, that is to say that by the time the GLAST construction effort has dwindled to a negligible level, new projects will be in place that represent twice the current GLAST effort. We anticipate 150-200 laboratory technical personnel engaged in this program a decade from now.

When the scenarios process started, the Director and Deputy Director of KIPAC had just been appointed and it was felt that it would not be helpful to the founding of the institute to use the scenarios process to identify specific projects for future KIPAC involvement. Rather a more productive strategy was simply to try to identify the level of effort or scale of the particle astrophysics and cosmology effort. In fact, KIPAC launched its activities far more quickly than anticipated and has taken rapid steps towards participation in two major cosmology projects JDEM and LSST. The level of effort in the future scenarios has been scaled to the known GLAST involvement and the anticipated participation in these new endeavors. It is anticipated that over the next ten years there will be further new SLAC initiatives in this area coming from KIPAC. However, it would be premature to call those out in detail at this time.

4 Scenarios

In developing scenarios for the future of SLAC, the invariance of the scale of SLAC's linear collider effort simplified things greatly. The type of effort is not an invariant and therefore the long-term future of the laboratory is potentially quite different depending on these downstream decisions. The scenarios focused on the major programs that would drive the size of the laboratory. Smaller programs that were considered as attractive science opportunities for SLAC to be involved in but which may or may not be pursued (e.g., EXO, LHC participation), were not included in the scenarios; however, as the scale of effort is relatively small, the conclusions of the study do not depend on the details of their inclusion. The driving program elements that shape the future of SLAC are:

- The involvement with the linear collider
- The future of the B-factory program
- The SSRL (synchrotron light) program
- Particle astrophysics and cosmology
- The program of advanced accelerator R&D

A programmatic assumption that the committee did make was that a 10^{36} B-factory could not coexist in the US with a US-sited linear collider. This was a constraint suggested by the HEPAP long-range panel and endorsed by the director of the laboratory.

Finally, in evaluating the scenarios, staffing levels (FTE's) at the lab were chosen as a measure of the 'size' of the laboratory and we looked at how the research resources were distributed among the different pillars of the program.

Four scenarios were evaluated in detail. The driving program elements that shaped those scenarios were:

- Scenario I
    - Major participation in a linear collider whether it be US or non-US sited
    - SPEAR3, LCLS as planned
    - No B-factory upgrades past 3 x 10^{34} $cm^{-2}s^{-1}$; B-factory turns off in 2010
    - Full linac capability preserved
    - Particle astrophysics and cosmology doubling in 10 years
    - Advanced accelerator R&D doubling in 10 years

➢ Scenario I results in 20% net growth in laboratory staff by 2015, dominated by the growth in the area of synchrotron radiation. The research program in 2015 is roughly evenly split between the synchrotron light program and the HEP program. The HEP on-site program is supporting in roughly equal proportions the linear collider, particle astrophysics, and accelerator R&D.

- Scenario II
    - Major participation in a linear collider whether it be US or non-US sited

    - SPEAR3, LCLS as planned
    - B-factory upgrades to 2 x 10^{35} $cm^{-2}s^{-1}$ in 2010 with continued running past 2015
    - Particle astrophysics and cosmology doubling in 10 years
    - Advanced accelerator R&D grows by 50%
- Scenario III
    - Linear collider sited in the US
    - SPEAR3, LCLS as planned
    - B factory at SLAC turns off in 2010; SLAC participates in a B-factory upgrade to 10^{35} - 10^{36} $cm^{-2}s^{-1}$at KEK with continued running past 2015
    - Full linac capability preserved
    - Particle astrophysics and cosmology doubling in 10 years
    - Advanced accelerator R&D doubling in 10 years
- Scenario IV
    - Linear collider sited outside US
    - SPEAR3, LCLS as planned
    - SLAC B-factory upgrades to 10^{36} $cm^{-2}s^{-1}$ in 2010 with continued running past 2015
    - Particle astrophysics and cosmology doubling in 10 years
    - Advanced accelerator R&D grows by 50%

➢ Scenario IV results in 30% net growth in laboratory staff by 2015. The research program in 2015 is approximately 1/3 the synchrotron light program and 2/3 the HEP program. 40% of the HEP experimental program is in the B-factory, 15% in accelerator R&D, and the remainder is split between the on-site linear collider effort and particle astrophysics and cosmology.

Additional manpower may be needed during the construction phases of the projects in the various scenarios. This is very dependent on the phasing of the projects in time. The above predictions for the total SLAC FTE count in 2015 assumes the LC construction to be complete by that time.

5 Conclusions

The Scenarios Committee was uniformly enthusiastic about the rich program of science in which SLAC would be engaged in all the scenarios that were studied. The pillars of the program are strong. The lab is flexible, able to respond to new advances and surprising results that will unfold as the next decade progresses. The breadth of the program, which leverages off of the core strengths and capabilities of the laboratory, is impressive and will continue to be so. The laboratory is diversifying without losing its sense of mission and focus. The directors of the lab, current and past, are to be commended for securing such a bright future for the institution.

This report lays out four scenarios for the long term future of SLAC. Which of these will occur depends partly on external events not completely under SLAC's control and partly on work that SLAC must do over the next few years. To keep these scenarios viable some planning and R&D

must be done in the next few years. This committee has not considered this work of the next few years in detail including the very real resource constraints. It encourages the laboratory to do this planning carefully so as to preserve the flexibility to choose among these scenarios as the future unfolds.

The committee did not anticipate that the scope of the linear collider effort should be independent of where the linear collider is located and what technology is chosen, which simplified the scenarios process greatly. However, faced with this conclusion, the committee did recognize that the different technical and site choices for the machine would impact the laboratory in very significant ways. Care needs to be taken in choosing the SLAC pieces of the linear collider participation to make sure that the very fruitful synergy between the SSRL and HEP accelerator technologies is preserved to the maximum extent. The committee wishes to stress that the conclusions of the scenarios study in no way suggest that the laboratory should diminish its commitment to the warm x-band RF technology and additionally, the committee recognizes that choice of a US site for the linear collider would enormously benefit the entire US HEP community.

The committee recommends that the laboratory consider participating in the luminosity upgrade program at the LHC to provide opportunities to the laboratory and the user community to engage with the high energy frontier in advance of the turn on of the linear collider. Whether or not the laboratory chooses to follow this recommendation depends on the availability of resources at the lab and is also closely coupled to developments in other elements of the program, in particular the pace of progress on the linear collider.

The scenarios study concluded that the level of effort in advanced accelerator R&D should grow with a continuing emphasis on engaging the intellectual resources of the user community in what is the most challenging problem for the future of the field. The accelerators at SLAC will continue to be invaluable tools in the pursuit of this science.

The committee recognized that the greatest variable in distinguishing the scenarios is the future of the B-factory program. The committee felt that the laboratory and community are still defining the physics case for such a facility and therefore included a broad suite of options in the scenarios.

The opportunities for synchrotron science on the SLAC site have been aggressively developed in the past five years. The committee did not seek to extensively assess and review the synchrotron program. There are clear general trends of significant growth that were adequate and relevant for the purposes of the study.

Given the recent birth of the Kavli Institute, the committee felt it would not be helpful to the founding of the institute to use the scenarios process to identify specific projects for future KIPAC involvement. Rather, the committee worked to identify the scale of the future particle astrophysics and cosmology effort and we see the effort at least doubling over the next decade.

The committee would like to stress that this attempt to lay out scenarios for the long term future of SLAC is being done at a time when the world high energy physics community is unified in supporting a high energy high luminosity e+e- linear collider as the highest priority next project for the field. However the timeline for the machine, its technology, and its location are all unknown. While the scenarios described are remarkably robust against decisions of location and technology for the linear collider, the high energy physics part of the program is not robust with respect to major changes in the timeline for construction of the machine. As the schedule for the linear collider becomes clearer in the next few years, we believe it would be appropriate to revisit the HEP elements of the scenarios and update them as necessary.

The committee deliberately avoided the question of 'What if there is no linear collider'. It was not in the charge. The committee felt strongly that 'no linear collider' is an issue for the field as a whole and it threatens the survival of a healthy US HEP program. It is not foremost an institutional issue for SLAC. In fact, the imperative would be to address the issue for the field first and SLAC would be prepared to help the community in that unfortunate situation. The steps taken in this study would inform that process.

Finally the scenarios committee was aware that in two of the four scenarios there is no frontier onsite high energy physics facility operating at the laboratory in 2015. The program is rich enough and the laboratory strong enough to be successful and to thrive in that situation. The committee noted that even without a forefront high energy physics facility on site, the linac will continue to be an essential part of the program. The linac is an important feature for possible upgrades to the LCLS, R&D for the linear collider and linear collider detector, and advanced accelerator R&D studies. The ubiquitous SLAC linac has enabled forefront science for 40 years on the SLAC site and is likely to do so for decades to come.

Appendix A

Charge for the SLAC Scenarios Study

Background

The world HEP community has decided that the next large accelerator project after the LHC should be a high energy, high luminosity e+e- linear collider. This will be a multi-billion dollar accelerator project with participation of major physics labs around the world. SLAC will be a major participant in the design, construction, operation and exploitation of this facility, independent of where it is sited and what technology is chosen. However the model for SLAC's participation has not yet been determined.

The PEP-II/BaBar program has an exciting future throughout this decade. The B physics program in the next decade will be shaped by what is learned in this decade and a next generation B factory is under consideration by the community and SLAC.

SLAC, in partnership with the Physics and Applied Physics departments on campus, has started a new Institute for Particle Astrophysics and Cosmology. Building on the experience with GLAST, SLAC and the Institute will be participating in new major initiatives in particle astrophysics throughout this decade and into the future.

As we look towards our future, what are the exciting physics opportunities for SLAC to be engaged in as we look forward to the next decade? Will they be on site, off site or in space? How do the projects we may be doing utilize the lab manpower and infrastructure? How does this depend on the linear collider technology choice and the siting of the linear collider?

Goal

This committee should prepare a white paper for the Laboratory Director entitled "Scenarios for the Future of SLAC". It should look at what may be happening at SLAC in the next decade while an international linear collider is being built and operated. This paper should be completed by October 1, 2003. Information for it should be gathered in an open fashion involving the SLAC faculty, staff and users. There are many possible scenarios. These should be reduced to some illustrative examples that are examined in detail to provide a picture of the size and vitality of the laboratory.

Appendix B

Membership of Scenarios Committee

Persis Drell (co-chair), SLAC Research Division

Tom Himel (co-chair), SLAC Technical Division

Lance Dixon (subgroup co-chair), SLAC Research Division

Ewan Paterson (subgroup co-chair), SLAC Technical Division

Tor Raubenheimer (subgroup co-chair), SLAC Technical Division

John Seeman (subgroup co-chair), SLAC Technical Division

Jim Brau, University of Oregon

Marty Breidenbach, SLAC Research Division

Pat Burchat, Stanford University

Eric Colby, SLAC Technical Division

Su Dong, SLAC Research Division

John Galayda, SLAC SSRL and Technical Division

JoAnne Hewett, SLAC Research Division

Bob Jacobsen, University of California, Berkeley

Steve Kahn, SLAC Research Division and Stanford University

Yannis Karyotakis, ANNECY, LAPP

Homer Neal, Yale University

Marc Ross, SLAC Technical Division

Bruce Schumm, University of California, Santa Cruz

Bob Siemann, SLAC Technical Division

Andy Wolski, LBNL

Appendix C
Scenarios Days

B Day (3/20/03): 10^{36} (or 2 x 10^{35}?) e^+e^- B factory
(M.Giorgi, R. Cahn, D. Hitlin, J. Seeman, M. Sullivan)

"An International Linear Collider and What it Might Mean for SLAC" (04/01/03):
(D. Burke)

Neutrino Physics Day (4/18/03):
(B. Kayser, G. Feldman, S. Wojcicki, S. Freedman, C. Prescott)

Colloquium on ITER with emphasis on how it is divided up and managed (04/21/03):
(R. Goldman)

LHC Day (4/24/03): Physics, detector and machine opportunities associated with LHC upgrades
(J. Strait, A. DeRoeck, D. Green)

Z/Higgs Day (5/1/03): Discussion of high-energy options for the SLAC site
(J. Gronberg, T. Raubenheimer, M. Peskin, M. Woods)

Two Beam Day (5/19/03): Discussion of advanced two-beam accelerator options
(D. Asner, R. Ruth, W. Wuensch, T. Katsouleas)

Colloquium on ALMA the large millimeter array in Chile (06/09/03):
(R. Brown)

Cosmology Day - Discussion of Astrophysics and Cosmology options (6/13/03):
(C. Hogan, E. Linder, G. Bernstein, R. Mushotzky)

Summaries of "Days" and wide open town meeting as part of the SLUO meeting (06/11/03)