Cornell Laboratory for Elementary-Particle Physics: New Perspectives

August 4, 2005

1 Introduction

The field of particle physics is approaching a new era. A multitude of evidence suggests that the energy scale of about 1 TeV will open a new vista onto nature. At this energy scale, the familiar particles that are the building blocks of the world around us, and even the most elusive quarks, leptons and neutrinos that we can produce in accelerators and the stars, may seem mundane. The interactions that we now know - electromagnetism, the weak force, the strong force and gravity, may turn out to be but a tiny corner of what nature has in store. And there may be dimensions of space beyond the familiar three. The discoveries at the TeV scale may shed light on some of the big open questions – what is mass? how does gravity relate to the other forces? what is the nature of space? what is the dark matter?

Until now, our only access to the TeV energy scale has been through precision measurements at lower energies. Even at accelerators with energies far below 1 TeV, particles and interactions from the TeV scale can make themselves felt indirectly by altering the properties and decay mechanisms of the quarks, leptons and gauge bosons. Just as the top quark influenced the decays of the Z boson, a Higgs-like particle can influence the mass of the W boson, or a heavy charged Higgs particle or a leptoquark might influence decays of the bottom quark.

Physicists at the Cornell Laboratory for Elementary Particle Physics (LEPP) are hunting for hints of TeV-scale physics in quark and lepton decays. Using the Cornell Electron Storage Ring (CESR, and now CESR-c), the experimental group is making some of the most precise studies of decays that might be affected by new phenomena, and is peeling off the mask of the strong interactions that could hide them. This work builds on an effort spanning 25 years that has mapped out the properties of bottom and charm quarks and the tau lepton and illuminated the strong and weak interactions that govern them. The accelerator and Superconducting RF accelerating (SRF) groups have made numerous innovations that put CESR at the luminosity frontier, making this work possible. The LEPP theory group is also engaged in this enterprise, with a strong program in heavy quark phenomena and in the physics that might enter at the TeV-scale and beyond.

Later in this decade, the exploration of the TeV scale will shift from indirect searches at the precision frontier to direct searches at the energy frontier. The new frontier will open at the Large Hadron Collider (LHC). In the next decade the International Linear Collider (ILC), a high energy, high luminosity e^+e^- collider, will expand on the LHC's discoveries. Accordingly, the program at LEPP will shift its focus from heavy flavor physics to the energy frontier. In the next few years, CESR will cease operation for elementary particle physics, and a new effort at the LHC will grow. The experimental, accelerator and SRF groups are already active in the ILC, and will expand their role. The particle theory group will increasingly focus its attention on TeV-scale physics and beyond.

Work at LEPP is connected to other scientific fields through the Cornell High Energy Synchrotron Source (CHESS), an x-ray facility at CESR. This connection will grow. Recently, Cornell accelerator physicists have developed a strategy for a brilliant x-ray source called the Energy Recovery Linac (ERL). With NSF support, the accelerator group is now developing the ERL design and prototyping key elements. The goal is construction of the ERL at Cornell. The ERL would have broad application in biology, geology, medical science and many other fields.

Particle physics is connected to cosmology. In the last few years, the WMAP experiment and supernova studies have shown that we understand only 5% of the matter in the universe, with the remainder made up by the mysterious dark matter and even more mysterious dark energy. What are the dark matter and dark energy? What pushed the exponential growth of the universe after the big bang? Where did the antimatter go? As LEPP physicists begin to explore these questions experimentally from the particle physics side, they envision a complementary program to explore these questions from vantage point of observational cosmology. Such an effort would mesh well with the lab's current work in theoretical astrophysics and cosmology. It would be a new effort, most likely as part of a larger enterprise arising at the departmental and inter-departmental level.

Thus, in response to the scientific revolutions of astrophysics and particle physics, LEPP envisions its own revolution. This revolution starts from the precision frontier at CESR, supported by powerful groups in accelerator physics, SRF, experimental particle physics and theoretical particle physics. It builds on these strengths, and moves to the frontiers of the TeV-scale, cosmology and astrophysics, and accelerator physics. The pages that follow describe the elements of this revolution.

2 Current Activities at LEPP

The Laboratory is engaged in a wide range of activities. Accelerator physics encompasses CESR-c operations and studies for CLEO and CHESS, the superconducting RF cavity research project (SRF), ILC design and R&D, and the ERL project. Experimental particle physics is currently focussed on CLEO-c operation and data analysis, but also includes ILC detector and software development and ILC physics studies. A new effort on LHC is now ramping up. Theoretical physics explores topics in phenomenology, field theory, string theory and astrophysics.

This section lists some of the highlights of the principal research areas.

2.1 Experimental Activities

CESR: The electron-positron storage ring operates 24-hours per day, 7 days per week, year-round (except for maintenance periods). The beams serve the particle physics community via CLEO, the x-ray science community via CHESS, and the accelerator physics community through direct studies of the accelerator itself.

The outstanding accomplishments of CESR over the last two and a half decades include the following: the first use of a permanent magnet final focus quadrupole in a colliding beam machine to reduce spot size; invention and implementation of the "pretzel" separation scheme so that multi-bunch beams could be circulated in a single ring machine and collided at a single IP; implementation of a crossing angle at the IP so that trains of closely spaced bunches could be stored but collisions restricted to a single point; use of single cell superconducting cavities in a high current, heavily beam loaded configuration to increase beam current and luminosity in CESR; instrumentation and analysis and control system software so that accelerator optical functions could be measured and corrected in real time; and finally, as a result of these innovations, the operation of the highest luminosity e^+e^- collider in the world for a decade.

With the transition to CESR-c we have carried out the design, engineering, fabrication, testing, and calibration of superferric high field damping wigglers in CESR. The wigglers have reduced the radiation damping time by an order of magnitude, making it possible for CESR to function at low energy with high luminosity, and have transformed CESR into the world's first wiggler dominated ring, a possible model for future ILC damping rings. Measurements of wiggler fields and their effects on beam dynamics demonstrated the accuracy of our understanding of the physics and the reliability of our modeling tools. In the CESR-c configuration we have achieved the world's highest luminosity for the charmonium state $\psi(3770)$ thus establishing the basis for CLEO-c operation.

CESR is unusual in that it is readily available to graduate students for their research. Over the last decade, nine students have earned PhD's in accelerator physics at Cornell.

CLEO: LEPP has played a central role in the conception and construction of the CLEO particle physics detector, and in the analysis of CLEO data. CLEO is a state-of-the-art general purpose spectrometer with charged particle tracking, particle identification, electromagnetic calorimetry, and muon detectors. The detector has been built, operated, and regularly upgraded over twenty-five years by the members of the CLEO collaboration, who also analyze its data. The Collaboration has published approximately 380 papers and produced over 100 PhD theses during this time. We have also pioneered new technologies in electromagnetic calorimetry that have been copied many times since, and have achieved performance in charged particle tracking that sets the standard for the rest of the world. CLEO's research papers span bottom, charm, and tau physics, and are among the most frequently cited in the experimental literature. Notable firsts include the discoveries of numerous particles (the B meson, upsilon states, charmed mesons, and charmed baryons); the first observations of penguin-mediated B meson decays; the first determination of the b-quark to u-quark transition rate that governs CP violation in the Standard Model. In addition, many precision measurements in the bottom quark system, particularly the determinations of the mixing matrix elements $|V_{ub}|$ and $|V_{cb}|$, remain competitive despite the larger data samples of the B factories.

LEPP is currently focussed on studying properties of the charm quark in the new incarnation of CLEO known as CLEO-c. The data already in hand, 3 million $\psi(2S)$ decays and 280 pb^{-1} collected at the $\psi(3770)$ peak, have shed new light on J/ψ and $\psi(2S)$ decays, revealed the h_c, and significantly improved precision in the D meson hadronic and semileptonic decays and $D \to \mu\nu$.

SRF: The SRF group has pursued the development of superconducting radio frequency cavities for particle acceleration for more than four decades. During this time the RF cavity properties have improved and are now approaching Q factors of 10^{11} and accelerating gradients of 45 MeV/m, which exceed current ILC goals and are approaching fundamental limits. Cavities designed and/or built here are in use at CESR, JLAB, the Canadian Light Source and the Taiwan Light Source. The DIAMOND Light Source now under construction in the UK also uses the Cornell developed system.

The SRF group was the founder of the TESLA collaboration which developed the baseline superconducting ILC design, and was the first to reach 25 MeV/m gradient thereby making the superconducting option for linear colliders a serious contender. It is now the final technology choice. Much of the SRF infrastructure installed at DESY is modeled after our facilities in Newman Lab. We have developed techniques to achieve high purity niobium and to process field emission sites and thus have overcome the major gradient limitations of thermal breakdown and field emission. Our scientific breakthroughs have been to understand the role of thermal conductivity, material purity, and the nature of RF breakdown.

The SRF group has also participated in the Muon Collider Collaboration to develop accelerating structures for the Neutrino Factory and is currently deeply involved in the ERL design, contributing to the design of the high brightness injector.

ILC: Many faculty and several Research Associates play key roles in the evolving program of the International Linear Collider (ILC). Gerald Dugan is the Regional Director for the Americas of the recently established Global Design Effort (GDE). Until very recently the Laboratory Director, Maury Tigner, chaired the main international governing body, the ILC Steering Committee, and several faculty members are chairs or members of other key committees in the ILC structure. Both Dugan and the late Joseph Rogers were members of the ILC Technical Review Committee. This group produced a 500 page summary of the technical status of competing linear collider designs, which was used extensively in arriving at the recent decision in favor of the superconducting technology. Ritchie Patterson sits on the World-Wide Study Organizing Committee which is the detector arm of the GDE, and Senior Physicist Daniel Peterson is on the World-Wide Study's Detector R&D Panel, which is internationally coordinating ILC detector technology R&D. On the national front, both Tigner and Dugan are members of the U.S. Linear Collider Steering Group and Dugan chairs the Accelerator Subcommittee of that Group. The Laboratory hosted the American Linear Collider Physics Group workshop in the summer of 2003, and both Lawrence Gibbons and Jim Alexander have served (are serving) on the executive board of this group.

The Laboratory championed early entry into ILC research and development and initiated the University Consortium for Linear Collider R&D (UCLC) to seek funding and carry out the R&D mission. Cornell, led by Dugan, now oversees funding of all university-based accelerator R&D. Peterson is leading a project to develop Time Projection Chamber technology and track reconstruction algorithms suitable for an ILC experiment. Seven Cornell faculty and Senior Research Associates, together with their graduate students, are working on aspects of the ILC design. They have made significant contributions to the design of a polarized positron source for the ILC, to its damping rings and to the development of novel injection/extraction schemes. They are also studying beam dynamics and alignment issues, strategies for bunch compression, beam instrumentation, and control systems within the context of the Global Accelerator Network. The SRF group is studying a number of issues related to the structures that will accelerate the beams in the linear collider, and has, for example, recently achieved some of the highest field gradients to date in these devices.

ERL: The Energy Recovery Linac is a novel scheme, now under design and development within the Laboratory, that will produce brilliant and highly coherent x-ray beams using very low emittance electron bunches. Furthermore, the x-ray pulses would be extremely short to allow time resolved experiments. The key is to accelerate each bunch once by RF cavities, use it for x-ray production, and then recapture its energy by decelerating it in the same cavities. The recaptured energy is stored in the cavities' fields and is used to accelerate new electrons. Because energy has to be continuously transferred from a decelerating bunch to an accelerating bunch, the cavities must be operated continuously with high fields. Only superconducting RF (SRF) cavities can do that without overheating. SRF cavities are thus essential to the whole plan, as noted in the original paper by Maury Tigner (A Possible Apparatus for Electron Clashing-Beam Experiments, M. Tigner, Nuovo Cimento Vol 37, 1228-1231,1965). At the present time the ERL development is strongly supported by the University and multiple review panels, including members from ANL, BESSY, DESY, FNAL, JLAB, SNS, and UW-Madison. Funding for a prototype injector to demonstrate the feasibility of the concept has recently been received. We expect to submit a proposal for a hard x-ray facility based on the CESR ring in 3 to 4 years.

2.2 Activities in Theoretical Particle Physics and Astrophysics

The particle theory group at Cornell is one of the few groups in the world to have experts representing practically all directions of cutting-edge research in theoretical particle physics: particle physics within the Standard Model, particle physics beyond the Standard Model (including string theory), formal research in quantum field theories, and research in astrophysics and cosmology.

The members of this group are currently pursuing research on some of the most important topics from a variety of fields in high-energy and astrophysics theory:

Flavor Physics: In the field of Standard Model physics, Lepage uses lattice gauge theory calculations to predict observables related to B and D meson physics at a few percent level, some of which will be measured soon with comparable accuracy at CLEO-c. Neubert uses the recently developed soft-collinear effective theory and QCD factorization theorems to study processes of great importance in heavy-flavor phenomenology. He has proposed several methods for precision measurements of the parameters of the unitarity triangle (in particular, the weak phases γ and α, and the magnitude of V_{ub}), many of which are currently being applied by the BaBar and Belle collaborations. He also studies signals of New Physics in the rare decays of B mesons.

TeV-scale Physics: In the area of physics beyond the Standard Model, Csáki and Perelstein study theories with extra dimensions and/or supersymmetry, with particular emphasis on applications to possible new mechanisms for electroweak symmetry breaking – perhaps the most pressing issue in particle physics today. Csáki has recently proposed a new class of so-called "Higgs-less" models, in which the electroweak symmetry is broken by boundary conditions on 3-branes in extra dimensions. In these theories a fundamental scalar Higgs particle does not exist, yet unitarity in W-boson scattering processes is preserved. He is also interested in more formal investigations of strong interactions in SUSY gauge theories. Perelstein's work focuses on collider phenomenology at the TeV scale, and the interface between particle physics and cosmology.

Field Theory: LeClair studies quantum field theories in low dimensions and their applications to condensed matter systems, in particular disordered systems and quantum Hall transitions. These investigations have revealed novel renormalization-group flows, for example exhibiting limit-cycle behavior. LeClair also works on finite-temperature field theory and conformal field theories in any dimension.

Cosmology and Astrophysics: Tye addresses the consequences of brane inflation both from string theory and an effective theory point of view. His recent work explores the interplay between superstring theory and cosmology. In particular, he has proposed that the inflationary scenario in the early Universe may be realized as brane inflation in the brane world of superstring theory. He has also studied cosmic strings, which are fundamental strings/branes stretched to cosmological sizes, and could therefore offer a crucial observational window to superstring theory.

Teukolsky, Flanagan, York and Wasserman study topics in general relativity, relativistic astrophysics and cosmology. Flanagan focuses on the physics of strong gravitational fields, developing quantitative models of processes involving neutron stars, black holes, and the early Universe, which are useful for comparison with data from gravitational wave detectors such as LIGO. He also studies models of the early Universe involving extra dimensions and membranes, mathematical issues in classical and semiclassical general relativity, and dark energy. Teukolsky is engaged in computational astrophysics, concentrating on solving Einstein's equations of general relativity by computer. He has also worked on naked singularities in general relativity; the properties of rapidly rotating neutron stars, exploding neutron stars, relativistic stellar dynamics and planets around pulsars. Wasserman's recent research includes string cosmology, studying superfluids and superconductors in the spin of neutron stars, and the nonlinear dynamics of interacting modes in neutron stars. York is developing formulations of Einstein's equations that can be used to simulate realistic astrophysical scenarios and works on statistical mechanics in the presence of relativistic gravitational fields. The astrophysics group works closely with colleagues in the Astronomy Department; indeed, all hold joint appointments in the two departments.

2.3 LEPP and the World

The Laboratory has long been at the forefront in both accelerator physics and particle physics. We have noted above some of the many scientific accomplishments of the subgroups within the Laboratory.

In addition, our faculty members sit on many of the major committees and panels in the international particle and accelerator physics community. A snapshot of our last few years of service to the community, provided in Appendix A, includes the membership or chairmanship of committees and panels serving the following communities, agencies, laboratories, and organizations: Fermilab, CERN, SLAC, KEK, DOE, NSF, and many others. The Laboratory hosts numerous conferences, workshops, and summer schools, some recent ones of which are listed in Appendix B. And the Laboratory is committed to an extensive program of outreach with a full-time Coordinator, and over the past several years has conducted over 150 programs in local schools and organizations, conducted more than 4000 tours of the Laboratory, and distributed 275 copies of the Laboratory educational video.

3 Paths to the Future

The scientific program of CESR and CLEO, and the production of x-rays for CHESS has given the Laboratory an extremely rich source of physics for more than two decades. With the advent of the B-factories at Stanford and at KEK (Japan), the luminosity frontier shifted to these new machines, and our Laboratory began the process of designing a different future for its particle physics endeavours. Our approach to this, which will be described in more detail below, has been systematic and thorough, and has involved a wide spectrum of Laboratory personnel. At the same time the Laboratory has undertaken to propose a large-scale accelerator project, the ERL, and has begun to start building the staff to prepare designs and proposals. If successful, the ERL will give a new life to the local program and interact with the particle physics endeavours in important ways.

3.1 Our Strategy for Future Design

Beginning in 2000, we held a series of internal meetings and micro-workshops involving LEPP faculty, both experimental and theoretical, to identify our long-range physics interests and explore the options for future engagements. We invited outside speakers to give seminars and participate in "roundtable discussions" on the principle topics that emerged from this process. The result was a unanimous decision to set our sights on the high energy frontier at a linear collider.

More recently the experimental group undertook a similar process to reexamine our physics interests and formulate a plan for the mid-term period between the end of CLEO-c and the start of ILC physics. Once again, at a series of internal meetings and micro-workshops all HEP faculty and Research Associates systematically listed and studied options, and invited outside speakers for seminars and extended discussions. Driven by our desire to work at the energy frontier and the opportunity to contribute our skills, we emerged from this process with a decision to join one of the experiments at the LHC, and we have since become members of CMS.

More details of our plans follow.

3.2 Scientific Goals

3.2.1 Experimental Particle Physics

The CLEO-c program is rich with potential. It will put weak interactions under a microscope, and provide crisp new data on the strong interaction at the same time that the field of Lattice QCD will reach full power on the theoretical side. Data-taking will continue through to the end of the current funding agreement, which ends March 31, 2008, and we expect that data analysis will continue for a couple of years beyond that.

We are now launching our effort on CMS. We plan to contribute to the pixel detectors, initially through calibration and monitoring, to charged particle reconstruction, to the electromagnetic calorimeter, and to the core software. These projects were chosen because they match gaps in CMS and because they build on the expertise of the group. LEPP physicists were principal players in CLEO's silicon vertex detector; they led the development and calibration of the CLEO CsI electromagnetic calorimeter, which has been hugely successful and has since been echoed at BaBar and Belle; they were responsible for the highly efficient CLEO charged particle track reconstruction; and they designed and implemented the CLEO software infrastructure, which is notable for being both relatively light-weight and meeting physicist needs. Two new Assistant Professors, Thom and Wittich, now on CDF, bring with them expertise in hadron collider physics. Our CMS effort will ramp up as CLEO ramps down.

The ILC is our central long-range goal. The experimental group will continue TPC R&D and contribution to ILC organization, and ultimately, its LHC activity will taper off to make room to expand the ILC effort.

3.2.2 Accelerator Physics

In accelerator physics we have three distinct and highly active areas.

CESR: The CESR group is currently focussed on the CESR-c machine, a complicated and highly non-linear accelerator due to the wiggler magnets inserted in the ring to cool the beam. For accelerator physics the challenges are significant, and also provide a rigorous proving ground for technologies that will underlie essential components (damping rings) of the future ILC. Operation of CESR for particle physics will continue to the 2008 date noted above, and there will be continued operation of the machine as an x-ray source following cessation of colliding beam mode.

The faculty most involved in CESR are also engaged in ILC accelerator physics. We anticipate continued effort on the positron source, the damping ring design, machine simulation programs, control systems, and instrumentation. Some of these, particularly the simulation and instrumentation projects, offer natural opportunities for the experimental particle physicists to join and contribute to ILC accelerator physics. Furthermore they would be beneficial for planning, simulation, and control of an ERL at Cornell. LEPP's long-term role in the ILC will blend our expertise and capabilities with the needs of the machine.

ERL: The ERL group is currently engaged in the design and development of the ERL and prototyping critical components. Assuming success with long-term funding, this group will grow to become the dominant enterprise in Wilson Laboratory. Under a scenario in which the ERL is funded, the prospects for future accelerator physics with a local machine are extremely bright and we anticipate numerous challenging problems and PhD thesis topics. The ERL is being planned as an extension of CESR and collaboration between the CESR group and the ERL group is therefore essential. In the fields of electron sources, beam optics, diagnostics, collimation, controls, linac simulation, and SRF, a strong symbiosis of ERL work and ILC work is possible.

SRF: The SRF group is and will continue to press the frontier of technology in superconducting RF cavities, and will contribute to both the ERL and to the ILC.

3.2.3 Theoretical Particle Physics and Astrophysics

Flavor Physics: Flavor physics with heavy quarks will remain at the forefront of experimental and theoretical particle physics. The present B-factories at SLAC and KEK look forward to several more years of data taking, while CLEO-c continues to deliver high-precision data on charm physics. A next generation B-physics experiment at a hadron collider (LHC-b) is under construction. There remain some fundamental open questions concerning the flavor sector of elementary-particle physics, whose study promises great discoveries. The LEPP theory group will continue its strong effort on flavor physics and lattice QCD as long as we feel that this is warranted by the physics under investigation.

TeV-scale physics: The main event in the next five years will be the turn-on of the Large Hadron Collider (LHC) at CERN, currently expected to happen in 2007, which will finally provide direct experimental tests of our ideas about physics at the TeV scale. It is likely that this event will change in a rather significant way the priorities in particle physics in general, and particle theory in particular. There is likely to be less interest in formal (string) theory, and many of the current models of physics beyond the Standard Model will be discarded. One will quickly (after a year or two of LHC running) focus on a few viable models, and there will be a much more lively interactions among theorists and experimentalists. As a result, the research in the LEPP theory group may also become more data-driven (and consequently more exciting) once the LHC is fully operational, as is already the case for the current research on B physics. We find this highly satisfactory.

Field Theory: LeClair's research will move away from condensed matter applications and back toward relativistic particle physics, with particular emphasis on pursuing his recent approach to finite-temperature quantum field theory and possibly its applications to cosmology.

Cosmology and Astrophysics: At the same time, developments in cosmology promise further surprises and significant revelations about the workings of the Universe at large. The LEPP theory group will continue a strong research effort in string cosmology. Also, if the interest in cosmic strings in the astrophysics community increases dramatically in the next few years (e.g., due to some emerging supporting evidence), some of its members may redirect their research in a more observational or phenomenological direction. Gravitational wave astronomy is already advancing with the operation of LIGO, and the upgrade to advanced LIGO as well as the eventual launch of LISA will open up a broad range of high and low frequency phenomena to investigation via gravitational waves. The quest for computing the coalescence of black hole and neutron star binaries numerically is becoming increasingly urgent with the advent of gravitational wave observatories, and we can expect heightened activity along these lines at Cornell.

3.3 New Direction: Observational Cosmology and Astrophysics

The last two decades have seen the dramatic emergence of overlap between particle physics and astrophysics and cosmology. This is most evident in cosmology which now probes with remarkable precision features of the early universe. We are moving into a period in which we can exploit the universe itself as a superb particle physics experiment. At the same time, we will need to understand particle physics better if we are to understand the birth of the universe. Was there inflation? If so, what is the inflaton field? What is dark matter? What are its detailed properties, and how does it fit into our understanding of particle physics? What is the stuff we have named dark energy? Why don't "obvious" calculations of vacuum energy density come anywhere close to characterizing the observed amount of negative pressure in the universe? How will the next phase of accelerator-based particle physics – when we explore the Higgs sector, possibly the supersymmetric particle spectrum – affect our understanding of the evolution of the universe and its contents?

In the wake of this profound confluence of intellectual streams, neither particle physics nor astrophysics will be the same again. We believe that Cornell's Physics and Astronomy departments shouldn't be either.

Currently we have a strong program in theoretical astrophysics and cosmology with four distinguished faculty members (Teukolsky, Wasserman, Flanagan, York) in joint appointments with Physics and with Astronomy and Space Sciences, and a particle theorist (Tye) currently working mainly on cosmological issues. An observational component in our cosmology enterprise is important to fill out the intellectual mission of both the astrophysicists and the particle physicists. Because of the overlap of scientific interests and goals, we propose that this new component be developed with resources from this Laboratory, the Department of Physics, and the Astronomy and Space Sciences Department, with support from the College of Arts and Sciences.

As with the program to design the future of particle physics for the Laboratory, we investigated the opportunities and possibilities for including astrophysics and cosmology in the LEPP experimental research portfolio. Using the technique of meetings and micro-workshops and outside speakers, we have examined key issues and current status of the major areas of observational astroparticle physics. From this has emerged a consensus that Cosmic Microwave Background (CMB) and gravitational wave probes are likely to offer the most profound view into the early universe and the role of fundamental particle physics in shaping the universe we live in today. We have also engaged our colleagues in Astronomy and Space Sciences and found strong support there for our expressions of interest in these fields.

Much remains to be done to realize this goal. We expect however that now and for at least some decades to come, cosmology will be a prominent and important field of physics, and we should therefore have a solid observational component here at Cornell.

3.4 Institutional Goals

In the spectrum of particle physics laboratories and research groups across the country, Cornell's Laboratory for Elementary-Particle Physics has several unusual and distinctive traditions which we believe are strengths to be sustained, nurtured, and built upon as we go forward into the future.

First and foremost, we have had a history of coherence of effort, and have focussed the Laboratory's collective efforts on rather few projects. With occasional exceptions the bulk of the faculty has concentrated on the CESR-CLEO program for more than 25 years. Such tight coupling among so many faculty members over such a long time is unusual; it has been a source of great strength and has allowed us to accomplish large scale projects with modest resources. Boundaries are softly drawn. Particle physicists were key players in the design and construction of the CESR accelerator, and the operation of CESR and CLEO together over many years has ensured a continuing network of interrelationships and intellectual crossfeed. Laboratory space and facilities are commonly shared and Laboratory resources are redirected easily to projects that need them, when they need them. Our plan for the future is to continue this unique structure of scientific and sociological coherence.

Second, the program of research in particle accelerators which includes a world-class e^+e^- collider, a premiere x-ray source, and a research group that leads the field in SRF technology is unique today among universities and is a foundation for our future as much as it has been the key element in our history. Over many decades Cornell has been a primary site of academic training in accelerator physics, and former students with PhDs in accelerator physics from this department now populate the highest levels of leading laboratories. Accelerator physics is a growing and expanding field with new challenges coming both from particle physics and from x-ray science. We want to continue our historical strength in accelerator physics and maintain the diversity and vigor of the program. A future program encompassing work locally on the ERL and on SRF, and remotely on the ILC and possibly on the LHC, should be strong and synergistic, and will be unique in the research programs of North American universities.

Third, the overall coherence of the Laboratory program noted above has been particularly pronounced within the experimental particle physics group where it has made possible many significant accomplishments in the field of heavy quark physics. The evolution of this coherence was an outgrowth of the severe demands of maintaining a large scale on-site particle physics program, but it can be a powerful resource as we move into a future that includes substantial off-site research. Experimental particle physics is a field that defines the meaning of "big science", and in this environment size and coherence of effort is broadly empowering. Despite some loss of scientific variety and some burden of institutional inertia that inevitably accompanies such a structure, the sheer strength and ability to take on and succeed in large tasks is a strong motivation to persevere in this arrangement.

3.5 Infrastructure

The ability to accomplish ambitious goals in the arena of big science depends in part on the availability of suitably scaled infrastructure such as shops, technicians, and computer facilities. The Laboratory infrastructure and resources which provide much of the strength of our institution are largely determined by the scale of local facilities. Currently this means the operation of CESR, CHESS, and CLEO; in the future it will mean the construction and operation of the ERL.

That last clause is a nontrivial observation. It suggests a reversal of the present and historical pattern where x-ray science has thrived because particle physics built, operated, and funded most of the infrastructure. It paints a picture in which future particle physics, and the accelerator physics closely allied with particle physics, will be able to thrive in part because an ERL will provide laboratory infrastructure on a scale that enables these sciences. In this Laboratory, x-ray science and particle physics are and have always been in a deeply symbiotic relationship, and we expect that to continue – even if some of the roles are reversed – and in fact we propose to move forward

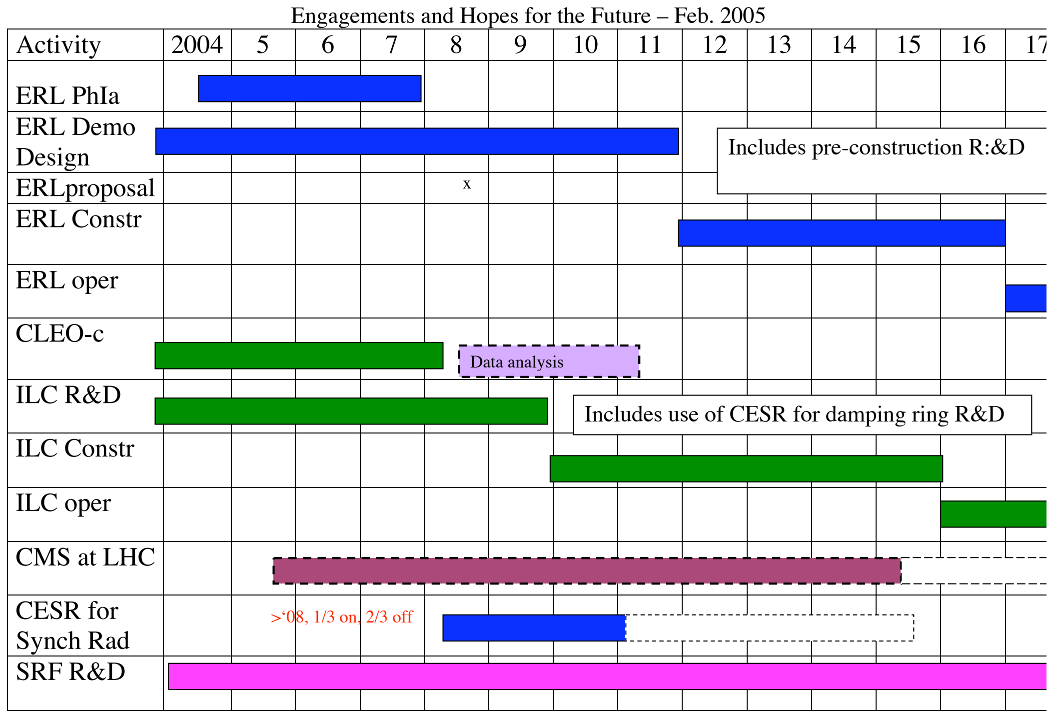

Figure 1: Timetable of planned activities for the next 12 years. Transition dates reflect our best guess of the earliest plausible time for activities to begin or end.

under a plan to maintain, enhance, and exploit this relationship.

We anticipate that the Laboratory structure – the organization chart – will have to evolve significantly to deal with the changes described above. The new structure must not only enable the on-site ERL project fully, but must also ensure that the off-site endeavours are maximally supported, and that the essential intellectual coherence and unity of the Laboratory is preserved.

3.6 Timetables

In planning for the future we take seriously the need to plan coherently across the entire Laboratory. Figure 1 shows in block diagrammatic form our vision of the evolving commitments and opportunities for the Laboratory. These commitments and opportunities include the items listed above: CLEO-c, energy frontier particle physics (ILC, LHC), CESR-c, CESR for x-rays, and ERL prototyping, construction, and eventual operation. SRF is ongoing throughout. The figure is a projection into the future and the dates are likely to change; we believe that this timetable is likely to be optimistic (fast).

Realization of these multi-component plans will require careful attention to logistical details, and we are presently studying the manpower issues closely. In particular we have examined various strategies for how to deploy a finite staff of faculty and Research Associates to cover the stated goals, working within the constraint that the LEPP Research Associate staff and faculty lines do not increase.

4 Conclusions

We are approaching the end of the CESR-CLEO era. It has been a productive 25 years, but the time has come to move on. We are engaged now in constructing a new future for the Laboratory to be guided by our scientific ambitions, driven by our technological capabilities, and founded on our historical strengths. There are new and genuinely exciting opportunities for us at the energy frontier of particle physics and at the cutting edge of accelerator physics. We envision moreover new possibilities to enrich our scientific endeavours by initiating a program in experimental astrophysics and cosmology.

We expect the next twenty-five years to be as productive and enriching as the last twenty-five.

Appendix A.

In addition to serving on the editorial boards of a number of journals and on various experiment review committees, LEPP faculty currently serve, or have recently served in the following roles on high level outside committees and panels:

- NSF: Chair, LIGO oversight committee; Chair, Ice Cube oversight committee; Member, EPP proposal evaluation panel; Members, Grant Selection Panels.
- DOE: Members, HEPAP; Member, P5; Subcommittee Chair, COV; Member, FNAL and Argonne Review.
- NRC: Member, NRC assessment of EPP.
- SLAC: Member, Scientific Policy Committee; Members, Program Advisory Committee; Member, NLC-Machine Advisory Committee; Member, PEP-II Machine Advisory Committee
- FNAL: Chair, Board of Overseers; Chair and member, Run II Advisory Council; Chair, Program Advisory Committee; Member, Accelerator Advisory Committee; Member, Long Range Planning Committee; Member, URA FNAL Review Committee.
- CERN: Chair, LHC Machine Advisory Committee; Member, LHC Experiments Committee (LHCC); Member, SPS Advisory Committee; Member, Scientific Policy Committee.
- BNL: Member, Director's External Advisory Committee
- KEK: Member, Collider Advisory Committee; Member, Program Advisory Committee.
- ILC: Chair, International Linear Collider Steering Committee; Regional Director for the Americas, Global Design Effort; two Subcommittee chairs, US Linear Collider Steering Group.

Appendix B.

List of recent or scheduled workshops and conferences held at LEPP:

- Lattice QCD (Lepage) January, 2000
- Charm Factory (Drell) May 5-7, 2001
- e^+e^- Factories 2001 (Rice) - Oct. 15-19, 2001
- LCCOM Workshop (Patterson) April 19, 2002
- Global Accelrator Network Workshop - March 21-23, 2002
- CLEO-c Symposium (Cassel) -June 19, 2003
- ERL Cryomodule and Prototype Refrigerator Workshop - March 3-5, 2003
- American Linear Collider Workshop (Patterson) - July, 2003
- Fast Luminosity Monitor Design Review - May 6, 2004
- ERL Injector Cryomodule Review (Padamsee) - September, 2004
- US Particle Accelerator School (Rubin) - June, 2005
- SRF 2005 Workshop (Padamsee) - July 10-15, 2005