# Understanding Matter, Energy, Space and Time:

# The Case for the Linear Collider

A summary of the scientific case for the $e^+ e^-$ Linear Collider, representing a broad consensus of the particle physics community.

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Over the past century, physicists have sought to explain the character of the matter and energy in our universe, to show how the basic forces of nature and the building blocks of matter come about, and to explore the fabric of space and time. In the past three decades, experiments at laboratories around the world have given us a descriptive framework called the *standard model.* These particle physics advances make a direct impact upon our understanding of the structure of the universe, both at its inception in the Big Bang, and in its evolution to the present and future. The final synthesis is not yet fully clear, but we know with confidence that major discoveries expanding the standard model paradigm will occur at the next generation of accelerators. The Large Hadron Collider (LHC) being built at CERN will take us into the discovery realm. The proposed $e^+e^-$ Linear Collider (LC) will extend the discoveries and provide a wealth of measurements that are essential for giving deeper understanding of their meaning, and pointing the way to further evolution of particle physics in the future.

A world-wide consensus has formed for a baseline LC project in which *positrons* ($e^+$) collide with *electrons* ($e^-$) at energies up to 500 GeV, with *luminosity* (the measure of the collision rate) above $10^{34}$ $cm^{-2}s^{-1}$. The energy should be upgradable to about 1 TeV. Above this firm baseline, several options are envisioned whose priority will depend upon the nature of the discoveries made at the LHC and in the initial LC operation.

This report was prepared by the community of high energy physicists[(1)], many of whom have participated in the World Wide Study of Physics and Detectors for a Future Linear $e^+e^-$ Collider[(2)]. In it, we summarize the scientific case for the LC, the accelerator complex, the nature of the experimental detectors needed, and the cooperative steps being taken by physicists around the world to achieve it, in language that we hope will be accessible to particle physicists, and more broadly to scientists in related disciplines. We hope that this document can also be useful as background for preparing the more general case to the public audience. More extensive discussions of the LC physics program and detectors can be found in Refs. (3), (4) and (5).

## 1. The scientific case for the Linear Collider

▪ *Where we stand today*

In the past thirty years, huge strides were made in understanding the interrelationships of the strong force that binds the nuclei, the electromagnetic force, and the weak force that causes radioactive decays and powers the sun. All three are now understood to be 'gauge theories' in which the symmetry of fields dictates the existence of force-carrying particles (the *gauge bosons*) that have one unit of spin and no mass. These ideas form the basis for the standard model, whose predictions have now been confirmed through hundreds of experimental measurements. The forces are exerted upon the quarks and leptons, the building blocks of matter, through gauge boson exchanges. The strong force is mediated by a set of eight gluons, and the electromagnetic force by the photon ($\gamma$). The weak force requires quite massive force carriers called the W and Z bosons to account for its short range. The three forces are distinguished by characteristic particle properties such as electric charge, to which each of the forces respond.

Though the electromagnetic and weak forces seem quite different in our laboratory experiments, we understand now that they are in fact two aspects of a unified whole. Experiments over the past two decades using accelerators at CERN, SLAC and Fermilab discovered the W and Z bosons, demonstrated their close connection to the photon, and firmly established the unified *electroweak interaction*. The puzzle of the massive W and Z bosons could be understood if the primordial weak and electromagnetic force carriers were originally massless, but acquire mass through an electroweak symmetry breaking mechanism. The standard model hypothesizes that this mechanism is associated with a Higgs boson, so far undetected, that permeates all space. In this theory the Higgs field surrenders three of its four components to give the $W^+$, $W^-$ and Z bosons their mass, leaving the fourth to form a new particle – the *Higgs boson*. This standard model Higgs boson should be discovered in experiments at sufficiently large collision energy. Although it has yet to be observed, the standard model predicts its properties precisely – its spin and internal quantum numbers; its decays to quarks, leptons, or gauge bosons; and its self-interaction. Only the Higgs boson's mass is not specified by the theory.

Over the years the wealth of high precision studies of W, Z and $\gamma$ properties, the direct observation of the massive top quark, and neutrino scattering rates have confirmed the validity of the standard model and have severely constrained possible alternatives. These studies give a range within which the Higgs boson mass should lie. From the direct searches, we know that the Higgs boson mass is larger than about 114 GeV. The precision measurements limit the Higgs mass to less than about 200 GeV in the context of the standard model, and only somewhat larger for allowed variant models. The most likely Higgs mass is in fact just above the present experimental lower mass limit.

The proton-antiproton Tevatron Collider now operating at Fermilab can discover some of the lower mass states involved in electroweak symmetry breaking. In 2007, the LHC now under construction at CERN will obtain its first collisions. The LHC, colliding protons with protons at 14 TeV, will discover a standard model Higgs boson over the full potential mass range, and should be sensitive to new physics into the several TeV range. The program for the Linear Collider will be set in the context of the discoveries made at the LHC.

- *Understanding the Higgs boson*

The prime goal for the next round of experimentation is finding the agent that gives mass to the gauge bosons, quarks and leptons. This quest offers an excellent illustration of how the LHC and the $e^+e^-$ Linear Collider will magnify each other's power. If the answer is the standard model Higgs boson, the LHC will see it. However, the backgrounds to the Higgs production process at the LHC are large, making the measurements of the couplings to quarks, quantum numbers, or Higgs self-couplings difficult. The LC can make the Higgs boson with little background, producing it in association with only one or two additional particles, and can therefore measure the Higgs properties much more accurately. Even if it decays into invisible particles, the Higgs can be easily seen and studied at the LC through its recoil from a visible Z boson.

The precision measurements at the LC are crucial for revealing the character of the Higgs boson. If the symmetry of the electroweak interaction is broken in a more complicated way than foreseen in the standard model, these same precision measurements, together with new very precise studies of the W and Z bosons and the top quark only possible at the LC, will strongly constrain the alternate picture.

- *New discoveries beyond the standard model*

Although the standard model with the simplest Higgs boson is in excellent agreement with all we have observed so far, there are very strong reasons for believing that this is far from the complete story. We now know of at least two disparate energy scales that operate for elementary particle physics: the Planck scale at about $10^{19}$ GeV where the strengths of gravity and the other interactions become comparable, and the electroweak scale at a few hundred GeV. In addition, the strengths of the strong, electromagnetic and weak forces become similar at about $10^{16}$ GeV where many theories suggest the possibility of grand unification of the three forces. However, an extrapolation of present measurements to higher energies with the simple standard model fails to provide exact unification. To achieve it, some new physics is required at the 100 – 1000 GeV scale. Moreover, the extreme disparity of the electroweak and Planck scales cannot be understood in the standard model; the Higgs, W and Z boson masses are all unstable to quantum fluctuations and would naturally rise to the Planck scale without some new physics at the few hundred GeV scale. This behavior, known as the *hierarchy problem*, gives us confidence that the standard model with its Higgs boson will be supplemented with new phenomena at the TeV scale and that these can be discovered by the LC or LHC.

One such possibility is the existence of new *supersymmetric* space and time coordinates, which brings a set of sister supersymmetric '*sparticles*' nearly identical to all the particles we presently know, save that the partner of a *fermion* is a *boson*, and vice versa. (Fermions such as electrons and quarks have ½ unit of intrinsic spin; bosons have spins of 0 or 1 unit.) We have seen no such supersymmetric particles in experiments to date, but there is reason to expect some of them below a few hundred GeV.

If supersymmetry exists and bears upon the hierarchy problem, we are confident that the LHC will discover it and observe some of the superpartners – in particular the sisters of the quarks and gluons. The partners of the electron, muon, neutrinos, $\gamma$, W, and Z are difficult to study precisely at the LHC, but their properties can be measured in detail at the LC. While the LHC has a larger mass reach for superpartners, the precision with which the LC can determine the mass of the accessible sparticles is substantially better (by about an order of magnitude) than for LHC. This is important for sorting out the kind of supersymmetric theory at work, and in pointing the way to how the supersymmetry itself is broken at much higher energies. For the accessible sparticles, the LC will be capable of measuring the full range of their defining properties such as mass, spin, parity, and the mixing parameters among the states of similar character.

In supersymmetry, there is more than one Higgs boson, and the LHC and LC give quite complementary capabilities to discover them and measure their properties. The LC is also unique in its ability to measure the mass of the lightest sparticle precisely. To understand the cosmological origin of this particle, it is necessary to establish its character as a partner of Higgs or of gauge bosons – and the measurements of its couplings at the LC will be unique in establishing this. Knowledge of the lightest particle properties will in turn permit the LHC experiments to make their measurements much more incisive. In many cases, each accelerator must provide crucial information for the other to maximize the sensitivity of its studies, so the combination is much more powerful than the sum of the two independent endeavors.

Other ideas to solve the hierarchy problem postulate extra spatial dimensions beyond the three that we know, or new particles at the several TeV scale. If such ideas are correct, we again expect observable consequences at the LHC and the LC and a synergy will exist between them. For example, the LC and LHC combined can deduce both the size and number of extra dimensions. The new states expected from extra dimensions could perhaps be sensed directly at the LHC, but the precision measurements at the LC can measure their effects even for particles well above the range of the direct measurements.

- *The benefit of precision measurements and the interplay of LHC and LC*

There are two distinct and complementary paths for gaining a new understanding of the structure of matter, space and time. One is the direct discovery of new phenomena, which requires accelerators operating at the energy scale of the new particles. The second is the inference of new physics at high energies through the precision measurement of phenomena at lower scales.

Historically these two paths have worked together to give a much more complete understanding than from either one alone. Data from $e^+e^-$ colliders analyzed in the context of the standard model pointed to the region where the top quark should be. The Tevatron hadron collider discovered the top quark in this region. Precision data from both hadron and electron-positron colliders were necessary for the prediction of the Higgs boson mass, and this knowledge directly influenced the program now in place at the upgraded hadron collider at Fermilab. These precision data form the basis for the LHC and LC programs for delineating the character of the Higgs boson and understanding the origin of mass.

The LHC and LC will offer mutually supporting views of the new physics world at the TeV scale. If new phenomena such as supersymmetric particles are observed at the few hundred GeV scale, both accelerators should see some of these new states. However due to the differences of hadron and electron processes, the states seen will be different, and knowledge of those from one program will enhance the studies at the other. Both programs can establish the existence of supersymmetry, but the precision measurements at the LC will also enable us to understand how it is constructed, and how supersymmetry itself relates to the very high energy scale connected with grand unification of forces or superstrings.

The interplay between $e^+e^-$ and hadron colliders follows a well-established pattern from past research. The W and Z gauge bosons were discovered at a hadron collider, but much of our understanding of their role in the unified electroweak interaction has come from $e^+e^-$ collisions. After indirect indications from lepton-hadron and hadron-hadron experiments, the gluons (carriers of the strong force) were discovered in $e^+e^-$ experiments. Subsequent elucidation of the nature of gluons and their role in quantum chromodynamics came from hadron-hadron, lepton-hadron and lepton-lepton colliders.

- *Cross connections*

We may expect new advances in our understanding of space, time and matter at high energies and in the early universe through connections between the linear collider experiments, neutrino and quark studies, cosmological and astrophysical measurements, and high energy nuclear physics. Each of these branches of science bring insights that help illuminate the larger view of the universe.

As discussed above, one of the main advances in particle physics in the past decade was the accelerator-based studies at the energy frontier leading to the prospect for Higgs boson discoveries and possible new phenomena such as supersymmetry. Another important front has been the rapid evolution of our knowledge about neutrinos. Experiments, particularly those at underground laboratories, have now demonstrated that neutrinos have non-zero mass and that they mix in a way analogous to the quarks, although the numerical values of masses and mixing angles are puzzling.

The small neutrino masses may suggest the presence of new physics at a scale near the grand unification energy. The connection between such a high energy scale glimpsed through the neutrino masses and that inferred from precision studies at the LC may prove to be deep and illuminating. Though not yet demonstrated experimentally, the possibility that charge conjugation and parity (CP) symmetry violation could occur for neutrinos, as well as for quarks, offers a potential opportunity to gain new understanding of the puzzling excess of matter over antimatter in the universe. The LC studies of CP violation effects in supersymmetric particles, taken together with the information from the quark and neutrino sectors, could lead to a more fundamental understanding of origin of the matter-antimatter asymmetry.

Increasingly, particle physics is intertwined with cosmology, and particle astrophysics, and the combination of ideas and methods brings qualitatively new insights.

Cosmologists have deduced from the measurements of the cosmic microwave background that there is almost exactly the right amount of matter and energy to close the universe, but the ordinary matter of stars and interstellar gas comprises only about 4% of the necessary material. Another 23% is inferred from galactic motions as ‘dark matter’. The best dark matter candidate to date is the lightest of the supersymmetric particles, which can be precisely studied at the LC. The final 73% or so of the universe’s matter is inferred from experiments that study supernova explosions using techniques of particle physics experiments, and is presently wholly mysterious. The standard model predicts that the Higgs boson would contribute far too much ‘dark energy’ to the universe, so some new physics beyond the standard model would be needed to counteract it. We may hope that the LC and LHC can give us a clue of what this new ingredient could be.

The ultra-high energy cosmic ray particles coming from outer space defy conventional explanation, and may well be harbingers of new particle physics at very high energies, comparable to what can be sensed through the precision measurements at the LHC and LC.

Future LHC and LC experiments will tell us how the unified electroweak force operates. Particle physics experiments have also brought understanding of the strong nuclear force between quarks and gluons at short distances, through experiments at hadron, $e^+e^-$ and electron-proton colliders. New nuclear physics experiments that collide gold ions are exploring the properties of the strong force at large quark separations, and are seeking evidence for a new state of matter where the quarks and gluons are freed from their imprisonment within protons and neutrons. The evolution of the early universe at just moments after the Big Bang is controlled by the character of the electroweak and strong forces revealed in these accelerator-based experiments.

The nature of the universe as a whole is explained by the discoveries being made in our terrestrial laboratories.

In summary, the key scientific points establishing the case for the LC are these:

- *We know enough now to predict with very high confidence that the linear collider, operating at energies up to 500 GeV, will be needed to understand how forces are related and the way mass is given to all particles.*

- *We are confident that the new physics that we expect beyond the standard model will be illuminated by measurements at both the LHC and the LC, through an intimate interplay of results from the two accelerators.*

- *The physics investigations envisioned at the LC are very broad and fundamental, and will require a leading edge program of research for many years.*

## 2. The linear collider facility

Research and development on the linear collider has been conducted continuously for over a decade, leading to very well-understood proposals. The linear collider complex will contain two accelerators, one for electrons and one for positrons, bringing beams into head-on collisions at the location of a large particle detector. To achieve the necessary collision energy, the overall complex will need to be about 30 km long. The challenges in the project are exemplified by the transverse beam sizes at collision (a few nanometers), by the requirement of providing very high electric field gradients to achieve the large energies, and by the exceptional control of the beams needed during the acceleration process.

The baseline collision energy dictated by the physics program outlined in Section 1 should be 500 GeV, with the capability to lower the energy to about 90 GeV for some measurements and calibrations. Several physics studies demand that the energy be adjustable so as to scan across particle production thresholds. The machine luminosity dictates the collision rate; to meet the physics goals it should be more than $10^{34}$ $cm^{-2}s^{-1}$ at 500 GeV. The ability to distinguish many interesting processes from each other, and from backgrounds due to known reactions, is enhanced by providing electrons whose spins are aligned along their direction in a *polarized beam*. The baseline electron beam polarization should be 80% or greater. This should be achievable.

It is almost certain that the new discoveries made during the initial operation at 500 GeV will lead to the need for subsequent measurements at higher energy, so the ability to upgrade the energy to around 1000 GeV is essential.

Two basic technologies exist today that could be chosen for building a linear collider: the TESLA design(4) pioneered at DESY in Hamburg Germany and the JLC/NLC design that emerged from a joint R&D program between SLAC in Stanford California and KEK in Tsukuba Japan. The main difference between the two technologies lies in the frequency of the electric fields used for acceleration. The lower frequency TESLA design employs superconducting radio frequency cavities, while the higher frequency JLC(3) and NLC(6) designs use room temperature accelerating structures. A comparison of the technical parameters, remaining R&D and risks has been made by a Technical Review Committee formed by the International Committee on Future Accelerators (ICFA) in 2001 (7). Both technologies were judged to be viable, and the costs should be comparable. The choices of technology and site will be addressed over the coming year or so. Meanwhile R&D continues on methods to use a low-energy high-intensity electron beam as the accelerating power source that may allow an even higher energy collider in the future.

The new information gained from the initial LC operation in its baseline configuration, and the results from the LHC and current accelerators, will influence the need for an extended capability of the LC facility. The options discussed in the following three paragraphs will have a different priority depending on what the initial investigations reveal, but the potential for adding them should be retained in the machine design.

The addition of positron beam polarization may be needed to perform precision studies of Z bosons, especially if the electroweak symmetry is found to be broken in a non-supersymmetric way. Positron polarization also offers a valuable tool for disentangling supersymmetric states, and can be used to enhance the rates for rare processes such as two Higgs boson production.

Although the initial operation of the LC will bring electrons and positrons into collision, there are possible scenarios for which considerable benefit would derive from studying collisions of two photons, an electron and photon, or two electrons. Reasonably intense and monochromatic beams of polarized photons could be formed by backscattering bright laser beams from accelerated electrons. The use of $\gamma\gamma$ collisions with tunable energy and polarization can give unique opportunities. For example, in supersymmetry, the two heaviest Higgs bosons should be nearly degenerate in mass, and overlapped when produced in $e^+e^-$ collisions. Choosing the appropriate photon beam polarization states, one can selectively produce one or the other. Use of $\gamma\gamma$ collisions gives a greater discovery reach for heavy Higgs bosons than is possible in $e^+e^-$ collisions. Other supersymmetry studies are enabled by collisions of $e^-$ and $\gamma$, or $e^-$ and $e^-$ beams, giving sensitivity to higher mass states or improved mass measurement precision.

Science has always demanded independent confirmations of new discoveries, and this will continue to be true for the physics to be explored at the LC. However, at the linear collider, the beams come into collision at only one location at a given time. Thus if there were independent detectors at two locations, they would take turn with the beams – with collisions alternating between the two at frequencies that might vary between a fraction of a second and months, as the needs dictate. Besides the general advantage of having independent crosschecks of new results, providing two collision points could allow the optimization of two detectors for different studies. For example, the conditions around the $\gamma\gamma$ collision point are different than those at the $e^+e^-$ interaction region and suggest differences in detectors. Similarly, the experimental requirements for a detector that seeks the very best precision measurements of Z boson decays at low beam energies differ from those for the detector studying supersymmetry at the very highest energies. Two-detector operation can improve the LC efficiency, since one detector could take data while maintenance is done on the other. Finally, there are sociological reasons for two detectors. Spreading the people who work on the linear collider over two experiments allows more workable collaborations in which the inventiveness of young physicists can flower more effectively, thus providing better opportunities for developing the pool of talented scientists that is a major societal benefit of the linear collider program. For all of these reasons it is desirable to plan for two interaction regions into which two well-optimized detectors can be placed.

## 3. Linear Collider detectors

The $e^+e^-$ linear collider provides an exceptionally clean experimental environment. The interacting particles are the beam particles themselves, so the energy and quantum state of the initial state are fixed, unlike at hadron colliders where the reactions are initiated by one of many partons present in the incident hadron. The LC does have some associated radiation (photons and neutrons) accompanying the beams, but this does not create major concerns for radiation damage. It is in part this clean environment that gives major advantages to the LC experiments, permitting a much more detailed understanding of the new physics.

However, the detectors at the LC will present larger challenges than those at the earlier $e^+e^-$ LEP and SLC colliders due to the complexity of the scientific goals discussed in Section 1: discovering the nature of the Higgs boson and exploring the ways in which the standard model must be extended.

The central goal of understanding the nature of the Higgs boson requires that its decays be cleanly distinguished. The most restrictive probe of the Higgs boson's character comes from the measurement of its couplings to quarks and gauge bosons. This requires the identification of particles that decay within a few hundred micrometers of the interaction point. Particles containing either a bottom or charm quark are short-lived, and can even be present simultaneously in an event. New technologies have become available in the past decade that can materially improve the short-distance decay measurements. The LC design allows such detectors to be placed closer to the interaction than in the past, improving the separated vertex capability. The vertex measurement must be complemented by very accurate charged particle momentum measurements using detectors outside the vertex detector.

A second example of the pressure on detector technology brought by the science goals comes in measuring the energies of particles decaying into quarks, producing high-energy *jets* of particles roughly collimated along the parent quark directions. Examples include the decay of the Higgs boson into two bottom quark jets, the decay of W and Z bosons into a pair of jets, and the top quark decay into three jets. The sensitivity of such studies and the ability to separate rare signals from background depend on the resolution that can be obtained for the jet energy. New ideas in jet energy measurement using a combination of accurate charged track momentum measurement and energy measurement of neutral particles in dense, highly granular calorimeters lead to experiment designs that can bring substantial improvement over that achieved in past collider detectors.

The coil of the solenoid magnet needed for the measurement of the momentum of charged tracks contains considerable material; if located in front of the calorimeter it would degrade its performance. Thus it is desirable to place the magnet coil behind the hadron calorimeter.

Some elements of the program emphasize other aspects of the detector design. The tendency of many supersymmetric particles to decay into tau leptons brings an increased demand for optimized tracking and calorimetry for their identification. The possibility that there will be new quasi-stable particles decaying far from the interaction region dictates a calorimeter that can measure the direction of particles within its volume, and this places special constraints on the segmentation of the calorimeter. There are many processes in non-standard-model scenarios that emphasize detection of particles near the beam lines, bringing the need to extend the coverage of the detectors to more forward zones than was provided in past detectors.

Over the past several years, groups around the world have developed new ideas for LC detectors, using both detailed simulations of performance and tests of prototypes. While variations exist in the detailed technology choices, there is broad agreement on the main character of the elements of a LC detector.

Moreover, the R&D program to develop the new detectors has now become a highly integrated world-wide effort. The International Working Group on Physics and Detectors has recently produced a document[(8)] outlining the main technology choices and the R&D issues remaining to be studied, and has given impetus for international consortia to pursue this research.

## 4. The international character of linear collider research

A major milestone was reached in 2001, when high level panels in Asia[(9)], Europe[(10)] and the US[(11)] brought forward recommendations regarding the linear collider and its place in the larger context of particle physics. These three panels, including physicists from the full spectrum of particle physics and related disciplines, gave remarkably similar recommendations stating that the highest priority should be given to a world-wide collaboration to build a high luminosity linear collider at an initial energy of about 500 GeV. Each region proposed that the LC could be sited in their region, but pledged cooperation no matter where it might be built. The unanimity of these recommendations is striking, and indicates that for the full world community, the linear collider is the highest priority for the next step in understanding the sub-microscopic world of elementary forces and particles.

These regional recommendations were amalgamated in June 2002, when the Consultative Group on High-Energy Physics presented a report to the OECD Global Science Forum. The executive summary of this report states as the first of its Principal Conclusions:

> *"The Consultative Group concurs with the world-wide consensus of the scientific community that a high-energy electron-positron collider is the next facility on the Road Map.*
>
> *"There should be a significant period of concurrent running of the LHC and the LC, requiring the LC to start operating before 2015. Given the long lead times for decision-making and for construction, consultations among interested countries should begin at a suitably-chosen time in the near future."*

For the past decade, large R&D programs on the linear collider have been mounted in three regions of the world – in Europe through programs originally centered at both DESY and CERN; in Japan at KEK, and in North America at SLAC and Cornell. Other laboratories and universities have now joined this work. The evaluation sponsored by ICFA of the technical characteristics of these initiatives is explicitly inter-regional and is balanced with experts from each of the participating world-wide laboratories.

Regional steering groups have been formed in Asia, Europe and North America to coordinate accelerator, physics and detector issues, and outreach and political affairs. A significant step was taken in July 2002, when a truly world-wide organization, the International Linear Collider Steering Committee reporting to ICFA, was established. In addition to coordination of the regional efforts on accelerators, physics and detectors, this group is charged with a global effort on outreach to the public and to governments, and with developing recommendations for the organization of the Linear Collider consortium. The Steering Committee is committed to developing a choice on the technology for building the LC in the near future.

Forming an effective organizational structure for a world-wide collaborative project of the magnitude of the LC will be a great challenge. Each participating country across the three regions must have sufficient responsibility to engage its accelerator and detector communities, and to keep the regional program healthy. New modes of collaboration are required, with effective use of computer grid networks for machine operation as well as for data analysis. A successful world cooperation on the LC will however set new norms for international collaboration that should serve as models for other realms of human endeavor.

## 5. Conclusions

- The scientific case for the linear collider rests solidly on recent achievements at accelerator laboratories and other experiments around the world. We are confident that new discoveries will emerge within the energy range covered by the first stage of the linear collider operation up to 500 GeV. This conclusion is supported by studies in all regions of the world.

- To maximize the understanding of new interactions and particles at high energies, concurrent operation of the LC and the LHC is needed.

- The results from the first phases of the LHC and LC will surely demand that higher $e^+e^-$ collision energies will be needed in future.

- The technical designs of the linear collider have proceeded on two broad fronts. Each technology has matured so as to form a viable basis for building a reliable accelerator.

- Several options for alternate beam particles and positron beam polarization capabilities could be beneficial for exploring new discoveries made in the early phase of LC operation. The necessary R&D effort and the flexibility to add these should be retained.

- The physics goals of the LC dictate that new state-of-the-art detectors be built. A vigorous international detector R&D program in the next few years is a high priority.

- There is active inter-regional cooperation on linear collider accelerator systems, physics studies and detector development. An International Linear Collider Steering Committee to coordinate scientific, technical and governmental aspects of the project has been formed. The mechanisms developed for managing the international LC project could serve as a template for future world collaboration projects.

## 6. References


1. The list of individuals who support the case made for the Linear Collider found in this document can be found at http://blueox.uoregon.edu/~lc/wwstudy/report-list .

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