A University Program of Accelerator and Detector Research for the International Linear Collider (vol. V)

Detector projects

Linear Collider Detector Research and Development Working Group

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Linear Collider Detector Research and Development Working Group

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Proposal for University-based Detector R&D for the International Linear Collider: Project Summary

At the start of the millenium, the world's particle physicists arrived at a consensus that an International Linear Collider (ILC) should be the next major facility for high energy physics. Since then, progress has been swift. Candidate technologies for the accelerator were developed, the community agreed on the technology to be used and now a global center to coordinate the completion of the design is forming. Nationally, the Department of Energy's Office of Science has developed a 20-year plan that identifies the ILC as its highest midterm priority.

Realizing the vision of the ILC will be a great challenge both technically and in timeliness. The technical challenges lie in both detector and accelerator areas and derive from the need for high luminosity and high precision of measurement. The timeliness challenge lies in the need to have significant overlap with the Large Hadron Collider (LHC) if the full synergy of the two approaches to the energy frontier is to be achieved. Thus it is imperative that the high-energy physics community marshal its resources to address these issues.

The detectors for the ILC are highly challenging. This is not always fully appreciated. While many advances in detector technology were required for the LHC experiments, different challenges must be addressed for the ILC experiments. To gain perspective, one may compare these ILC needs with those of the LHC. ILC detectors must have: inner vertex layers about 5 times closer to the interaction point; 30 times smaller vertex detector pixel sizes; 30 times thinner vertex detector layers; 6 times less material in the tracker; 10 times better track momentum resolution and 200 times higher granularity of the electromagnetic calorimeter. (See the Brau *et al.* report on ILC R&D). This proposal addresses key aspects of these requirements. In order to provide governments with a convincing design and cost estimate, in time for substantial overlap with the LHC, conceptual designs for the detectors will need to be developed in the next few years. This proposal seeks to take an important step towards that goal.

This proposal will have scientific impact beyond the ILC. The detector R&D will lead to advances in a number of technical fronts, complementing well the detector development done for the LHC. Detector technologies optimized to perform precision measurements in the low-radiation environment characteristic of a linear collider will have applications in other areas of high energy physics, as well as in other fields.

The collaborating groups have a strong history of outreach to undergraduates and K-12 students and teachers. The work supported by this proposal will be integrated into these outreach efforts. Students in K-12 classrooms, and undergraduates, will be introduced to the exciting energy frontier physics to be studied by the International Linear Collider, and the state-of-the-art technologies required for its implementation. This dissemination of the concepts explored by basic research in high-energy physics to students in their developing years will provide for an increased understanding of the field by the general public, and will foster the public's interest in science in general.

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Proposal for University-based Detector R&D for the International Linear Collider: Project Description

Introduction

This is a collaborative supplemental proposal by 37 U.S. university groups, 6 U.S. national and industrial laboratories, and 36 foreign institutions to carry out detector R&D for the ILC. Its 41 projects broadly cover the previously identified detector R&D needs of the International Linear Collider (ILC) [1]. Support for the projects in this proposal will provide urgent, supplemental support for high priority projects currently supported with annual subcontracts within the LCDRD program. This proposal derives from the high level of interest by university groups in the ILC, their excitement about the physics to be done with the instrument, and their conviction that the ILC represents the future of the field.

1. Preamble

In 1999, the International Committee for Future Accelerators (ICFA) recognized the world-wide consensus that the next large facility for particle physics should be an international high energy, high-luminosity, electron-positron linear collider. The strong recommendation in 2002 from the U.S. High Energy Physics Advisory Panel (HEPAP) [2] that such a collider be the highest priority of the U.S. program was paralleled in Europe and Asia. Each region recognized the central importance of the physics to be studied, the maturity of the accelerator designs being advanced at laboratories in the U.S., Germany and Japan, and the necessity for international cooperation.

Since then, progress on the ILC has been swift. Regional steering committees, charged with organizing and coordinating ILC activities in Asia, Europe and the Americas, have been formed, as has their global counterpart, the International Linear Collider Steering Committee (ILCSC). In 2003, the International Linear Collider Technical Review Committee (ILC-TRC) convened by the ILCSC reviewed two designs based on differing accelerator technologies and concluded that both were feasible [3]. Then, in 2004, an international panel recommended that the ILC be based on superconducting technology for the main accelerator. The world's major high energy labs have accepted that decision, and in November 2004, accelerator physicists gathered at KEK to identify the research required in order to complete the design. Currently, the ILCSC is forming the Global Design Effort, which will manage this research. At the national level, the U.S. Department of Energy announced inclusion of the ILC in its 20-year plan for new facilities, according it the highest priority among the mid-term projects under consideration. At the HEPAP meeting in February 2005, Ray Orbach, director of the DOE's Office of Science said that the ILC is "our highest priority for a future major facility.... Were going to work our hardest to bring the LC to these shores." In April, 2006, the EPP 2010 report was released, providing an assessment of the field of elementary particle physics and making recommendations for the future of the field; the report strongly supported aggressive R&D efforts in preparation for the ILC.

The response from the U.S. High Energy Physics community has been equally swift. In early 2002, physicists from U.S. universities and laboratories organized a series of workshops at Chicago, Fermilab, Cornell, SLAC and U.C. Santa Cruz aimed at identifying important directions for research and collaboration toward the ILC. These groups organized themselves into the University Consortium for Linear Collider R&D(UCLC) [4] in the context of NSF support and the Linear Collider Research and Development Working Group (LCRD) [5] in the context of DOE support, with the American Linear Collider Physics Group [6]coordinating the work of both groups. This year, with the development of a joint process for the review and funding of ILC R&D at universities, UCLC and LCRD have effectively merged, and they now comprise groups from 49 U.S. universities, 7 national and industrial research laboratories and 23 foreign institutions. All concerned are working together to coordinate their activities to the single task of building the linear collider.

2. Physics Goals of the International Linear Collider

The physics goals of the ILC are ambitious and compelling. Over the past decade, a wide variety of experiments has shown that elementary particle interactions at the TeV scale are dictated by an SU(3)×SU(2)×U(1) gauge symmetry. The non-zero masses of the W and Z particles imply, however, that the electroweak SU(2) × U(1) symmetry is broken spontaneously. We do not know how the symmetry is broken, and we will not know until the agents of electroweak symmetry breaking are produced directly in the laboratory and, also, are studied in precise detail. But we have every reason to believe that whatever is responsible for electroweak symmetry breaking will be accessible at the ILC.

Although we do not know the mechanism of electroweak symmetry breaking, we have some good hypotheses. In the so-called Standard Model, one doublet of scalar fields breaks the symmetry. This model has one physical Higgs particle, which is the window to electroweak symmetry breaking. The global consistency of precision electroweak measurements gives this model credence, and suggests that the Higgs boson is relatively light, $m_H < 200$ GeV. However, we know this model works poorly beyond TeV energies. A theoretically preferable scenario is based on supersymmetry (SUSY) at the expense of a whole new spectrum of fundamental particles and at least five Higgs states. But the lightest of these states looks much like the Standard Model Higgs, with nearly standard model couplings and a mass less than 200 GeV or so. Nature may break electroweak symmetry through some other mechanism, of course, but most realistic mechanisms we have imagined result in a Higgs boson or some related phenomena accessible to the ILC.

The TeV scale is the natural place to look for the agents of electroweak symmetry breaking. Thus, the ongoing Run 2 at Fermilab's Tevatron has a chance of getting the first glimpses of these phenomena. Starting later in the decade, CERN's LHC, with seven times the energy, will almost certainly observe the Higgs boson, and has a very good chance of discovering something else. Most high-energy physicists believe, however, that the LHC will not unravel the mysteries of symmetry breaking on its own. Experimentation at a linear e+e− collider provides information that cannot be obtained by other means. Let us just cite two examples. First, a series of cross section and branching ratio measurements will trace out a detailed profile of the Higgs boson, in a model-independent way, and incisively test whether its couplings are proportional to mass. Second, if SUSY is at play, the ILC can determine the lightest superpartners' masses with exquisite precision. The ILC measurements would be key to determining, for example, whether supersymmetric particles are the "dark matter" in the universe. In both these cases, the ILC adds critical information to what will be learned at the LHC. The ILC is the right next step for experimental high energy physics, and now is the time to take it in order to maximize the interplay of its results with those of the LHC.

The full scientific case for the ILC can be found in the Resource Book[7] prepared for Snowmass 2001 or the physics chapter of the TESLA Technical Design Report[8]. We believe the essential elements of the physics case have been made persuasively, and we are responding by banding together to meet the technical challenges that remain, so that the instrument can be built in a timely and cost-effective fashion.

3. The Need for Detector R&D for the International Linear Collider

Four candidate detector concepts have emerged for the ILC. The Global Large Detector (GLD) uses a large radius EM calorimeter (r = 2.1 meters) in order to separate showers, and hence allow precise jet energy measurements. Another design (SiD) is aimed at taking advantage of the precision of a silicon-tungsten EM calorimeter, and the timing resolution of a compact all-silicon tracker. A third concept, the Large Detector Concept (LDC) lies midway between the two, using a medium-sized gaseous tracker. A fourth concept is based on compensated calorimetry. In addition to EM calorimetry and tracking devices, all of the detector concepts incorporate precision vertex detectors, hadron calorimetry, muon identification, and critical beamline instrumentation.

For all of these detectors, the physics of the ILC demands significant advances over the currently available technologies. In comparison with the LHC, the radiation environment and data rates are mild, but the demands for precision are greater. Measurement of the Higgs branching fraction to b quarks, c quarks andgluons requires a beampipe with a radius 1/5 that of the LHC and a vertex detector with a pixel size that is smaller by a factor of 30. In order to tag a Higgs recoiling against a Z boson, the tracker must have only 1/6 of the material of the LHC trackers and a factor of ten better momentum resolution. And, in order to distinguish W and Z jets, the jet energy resolution must be better than 30% /√E(GeV), which is a factor of two better than the LHC target. The projects in this proposal are aimed at achieving these goals.

The time-scale for this R&D is already tight. If ILC construction is to begin in 2010, as is needed to optimize the interplay between the LHC and ILC programs, the detector technologies must be selected and the conceptual designs developed in the next few years. As a first step, by spring 2006 each candidate detector concept is to prepare a written outline that includes an introduction to the detector concept, a description of the detector, its expected performance, subsystem technology selections or options, status of ongoing studies and a list of needed R&D. More formal Conceptual Design Reports will accompany the accelerator's Technical Design Report shortly thereafter.

4. Broader Impact of the Work described in this Proposal

The proposed research will advance our technical capabilities in particle detection and electronics. It complements the detector research done for the LHC in that it focuses on precision measurement in a low radiation environment. This research will have applications for other experiments in high energy physics, and in other fields.

The proposal will also have impact in education and outreach. Numerous ongoing activities at the participating universities are aimed at K-12 students. For example, in the last two years, Notre Dame has involved 24 high school students in research. NIU sponsors a science camp for kids. Boston University sponsors a "Saturday Morning Physics" program and Cornell has initiated a monthly "Visiting Scientist Series". Boston and Cornell sponsor a one-day outreach programs for girls, and Michigan sponsors an annual Physics Olympiad. Cornell has co-hosted a session for local home-school students grades 4-9 and their parents, has coordinated a three-day workshop exposing secondary students to careers in accelerator physics and X-ray experimentation, and has designed and posted interactive web pages describing high-energy physics and accelerator research aimed at secondary school audiences and instructors. An estimated 1,400 people tour the Cornell research facility each year, and of these, approximately 500 are students. Those who can't visit the lab in person can watch the lab's video, or take an interactive tour of CESR and CLEO on the web. Boston and Wayne State have provided access to sophisticated research equipment to local high school classes.

One of the most effective ways to reach students is to reach their teachers. The groups at Berkeley Boston, UC Davis, UC San Diego, UC Santa Cruz, Chicago, Hawaii, Indiana, Iowa, Iowa State, Kansas, Kansas State, Notre Dame, Oklahoma, Oregon, Purdue, Rice, UT Arlington, Texas Tech, Washington and the national laboratories host Quarknet programs, while Cornell, Notre Dame and Wayne State host Research Experience for Teachers programs. In collaboration with multiple research centers on campus, Cornell has exposed over 250 high school physics teachers to resources on the Standard Model and provided educational materials, supplies and laboratory investigations for their students. Chicago, Cornell, Indiana, Kansas, Michigan, NIU, Notre Dame, Oregon, Purdue, Temple, Wayne State and many others have involved undergraduates in research, both individually and through Research Experience for Undergraduates programs. The Wayne State and Temple programs have been particularly effective at reaching minorities. At Cornell alone, approximately fifty undergraduate students hold research related jobs each year. Purdue opens their facilities to an undergraduate lab course each year.

New education and outreach efforts are centering on the ILC. Each year, at least 10 undergraduates will contribute to the projects in this proposal, either independently or through Research Experience for Undergraduates (REU) programs. Wherever possible, the ILC will be introduced into outreach activities aimed at K-12 students and the general public. These activities have already begun at the workshops of the American Linear Collider Physics Group. The 2003 ALCPG workshop in Arlington included exhibits for the public, and Rick van Kooten gave a lecture ”What is the Linear Collider?” for high school science teachers and undergraduates at the 2003 workshop at Cornell and (with Helen Quinn) for 450 science high school students at the 2002 workshop at Santa Cruz. At the ALCPG workshop in Snowmass outreach was an important component.

The broader impacts are discussed in more detail in the descriptions of the individual projects.

5. Structure of this project description

The detailed descriptions of the proposed detector R&D projects, including detailed budgets, statements of work, deliverables and broader impact, are provided following the references.

References

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[8] “Physics at an e+e- collider”, R. D. Heuer, D. Miller, F. Richard, P. Zerwas, TESLA Technical Design Report, Part III, http://tesla.desy.de/new_pages/TDR_CD/PartIII/physic.html19

Sections 3 - 7:

Detector Physics

Note: accelerator projects ("section 2") are documented elsewhere.