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

FY 2004 – FY 2006

University Consortium for Linear Collider R&D

and

Linear Collider Research and Development Working Group

November 24, 2003
17:00 CST

G.D. Gollin, editor
This final version of this document is available electronically at http://www.hep.uiuc.edu/LCRD/html_files/proposal.html. It has been modified since the preliminary drafts were posted.
Executive Summary

In the last several years, the international high energy physics community has come to a consensus that the next large project should be a TeV-scale linear collider. In the U.S. this is evidenced by the consensus reached at the Snowmass 2001 workshop and the subsequent statement by HEPAP:

We recommend that the highest priority of the U.S. program be a high-energy, high-luminosity, electron-positron linear collider, wherever it is built in the world. This facility is the next major step in the field and should be designed, built and operated as a fully international effort.

We also recommend that the United States take a leadership position in forming the international collaboration needed to develop a final design, build and operate this machine. The U.S. participation should be undertaken as a partnership between DOE and NSF, with the full involvement of the entire particle physics community....

This document is part of an effort to pursue a large-scale, national program of research and development leading to the design of a high energy linear electron-positron collider. It has been written by groups from 48 universities in 25 different states (in collaboration with five national and industrial laboratories, and eleven foreign institutions). The proposed research is intended to extend the ongoing work being done at labs and universities around the world. It comprises 68 different research projects which are requesting support at the initial level of $3M per year in a multi-year program.

The large participation and spontaneous assembly of many groups to form this research program expresses both the high level of interest in the university community to participate in this work and the desire to work together in a coordinated fashion to accomplish a common, important goal.

Both the Department of Energy and the National Science Foundation are interested in funding linear collider research and development. For administrative reasons, it is necessary to submit separate proposals in different formats to the agencies. From this document, which describes a coherent national research program in a fashion independent of funding source are derived the proposals submitted to the agencies late in 2003. The separate proposals will be submitted to the NSF and DOE by the University Consortium for Linear Collider R&D (UCLC) and the Linear Collider Research and Development Working Group participants (LCRD) respectively. UCLC and LCRD have closely coordinated their work to produce a single research plan which will later be split into its component parts for submission to the agencies.

---

The authors have worked closely with the preexisting American Linear Collider Physics Working Groups and the laboratories doing accelerator research to ensure that the most important issues were addressed.

Nearly half the proposed work is related to advancing accelerator technology. This is a change from the recent past when the vast majority of high energy physics R&D work performed at universities concerned detector development. In general, the critical path accelerator research needed for the Linear Collider is already underway at the national laboratories. Some of the work proposed here supports these critical path items. However, most of the proposed projects concentrate on the next level of development: issues that must be resolved in order to build the Linear Collider in a timely fashion, based on a solid design and reliable cost estimates.

There has been ongoing Linear Collider research and development work at laboratories and universities for the last twenty years. As the accelerator nears construction, more resources will be needed to finalize its design. The work proposed here will not only accomplish the short-term goals described above, but will also will train new scientists and engineers, contributing to the pool of talent and expertise that will be needed to accomplish the large task of building the Linear Collider accelerator and detector.
University Consortium for Linear Collider R&D  
and  
Linear Collider Research and Development Working Group

John M. Butler, Ulrich Heintz, Meenakshi Narain  
Boston University  
Dept. of Physics, 590 Commonwealth Avenue, Boston, MA 02215 (1)[3]

Yury Kolomensky  
University of California, Berkeley,  
Dept. of Physics, Berkeley, CA 94720 (2)[1]

Maxwell Chertok, David E. Pellett  
University of California, Davis  
Dept. of Physics, 1 Shields Avenue, Davis, CA 95616 (3)[2]

Gerard Andonian, David B. Cline, Joel England, Yasuo Fukui, Ryan Glasser, James  
Rosenzweig, Gil Travish, Feng Zhou  
University of California, Los Angeles  
Dept. of Physics and Astronomy, 405 Hilgard Ave., Los Angeles, CA 90095-1547 (4)[8]

Christian Flacco, Alex Grillo, Jurgen Kroseberg, Gavin Nesom,  
Hartmut Sadorzinski, Bruce Schumm, Ned Spencer, Abraham Seiden  
University of California, Santa Cruz  
Dept. of Physics, Inst. for Particle Physics, Nat Sci 2, Santa Cruz, CA 95064 (5)[8]

Ed Blucher, Kwang-Je Kim, Young-Kee Kim, Mark Oreglia  
University of Chicago  
The Enrico Fermi Institute, 5640 South Ellis Avenue, Chicago, IL, 60637 (6)[4]

Toshinori Abe, Bradford Dobos, Eric Erdos, Jeremiah Goodson, Jason Gray, Andrew  
Hahn, Alfonzo Martinez, Uriel Nauenberg, Joseph Proulx, Shenjian Chen  
University of Colorado  
Dept. of Physics, Boulder, CO 80309-0390 (7)[10]

David Warner, Robert Wilson  
Colorado State University  
Dept. of Physics, Fort Collins, CO 80523-1875 (8)[2..36..36]
Philip S. Baringer, Alice Bean, Eric Benavidez, David Z. Besson, Darius Gallagher, Carsten Hensel, Graham Wilson
University of Kansas
Dept. of Physics and Astronomy, Lawrence, Kansas 66045 (18)[7]

Lee Sawyer, Phillip Coane, Z. D. Greenwood, Neeti Parashar
Louisiana Technical University
Center for Applied Physics Studies, Institute for Micromanufacturing
W Arizona Ave., Ruston, Louisiana 71272-0046 (19)[4]

Ulrich Becker, Chiping Chen, Peter Fisher, Mark Hess
Massachusetts Institute of Technology
Dept. of Physics, MIT 44-120, Cambridge, MA, 02139 (20)[4]

Stanley S. Hertzbach
University of Massachusetts at Amherst
Dept. of Physics, 1126 Lederle Graduate Research Tower, Amherst, MA 01003-4525 (21)[1]

Dan Amidei, T. Blass, J. Deibel, S. Nyberg, K. Riles, H. Yang
University of Michigan
Dept. of Physics, Univ. of Michigan, Ann Arbor, MI 48109 (22)[6]

R. Poling, A. Smith
University of Minnesota
Dept. of Physics 116 Church Street S.E., Minneapolis, MN 55455 (23)[2]

Lucien Cremaldi, Igor Ostrovskii, D. Summers
University of Mississippi
Dept. of Physics and Astronomy, University, MS 38677 (24)[3]

Gabriele Bassi, James Ellison, Robert Warnock
University of New Mexico
\textsuperscript{1}Dept. of Mathematics and Statistics, Albuquerque, NM 87131
\textsuperscript{2}Stanford Linear Accelerator Center
2575 Sand Hill Road, Menlo Park, CA, 94025 (25)[3]

Jesse Ernst
State University of New York at Albany
Dept. of Physics, 1400 Washington Ave., Albany, NY 12222 (26)[1]

S. Mtingwa
North Carolina A&T State University
Dept. of Physics, 101 Marteena Hall, Greensboro, NC 27411 (27)[1]

1.0.7
Gerald Blazey, Court Bohn, Dhiman Chakraborty, Alexandre Dychkant, David Hedin, J.G. Lima, Arthur Maciel, M. Martin, J. McCormick, V. Rykalin, V. Zutshi
Northern Illinois University
Dept. of Physics and Northern Illinois Center for Accelerator and Detector Development, DeKalb, IL, 60115 (28)[11..43..140]

Michael Szleper, Mayda Velasco
Northwestern University
Dept. of Physics and Astronomy, Evanston, IL, 60208-3112 (29)[2]

Barry Baumbaugh, Michael Hildreth, D. Karmgard, A. Kharchilava, J. Marchant, M. McKenna, Randy Ruchti, Mitchell Wayne, Jadzia Warchol, M. Vigneault
University of Notre Dame
Dept. of Physics, 225 Nieuwland Science Hall, Notre Dame, IN, 46556-5670 (30)[10]

Ohio State University
Dept. of Physics, 174 W 18th Ave, Columbus, OH, 43210 (31)[6]

Rusty Boyd, Patrick Skubic, Michael G. Strauss
University of Oklahoma
Dept. of Physics, 440 West Brooks, Norman, OK, 73019 (32)[3]

J. Brau, Paul Csonka, E. Fitzgerald, Raymond Frey, I. Igonkina, N. Sinev, D. Strom, Eric Torrence
University of Oregon
Dept. of Physics, 1371 E 13th Avenue, Eugene, OR 97403 (33)[8]

Changguo Lu, Kirk T. McDonald
Princeton University
Dept. of Physics, Princeton, NJ 08544 (34)[2]

Kirk Arndt, Virgil Barnes, Daniela Bortoletto, J. Miyamoto, Ian Shipsey
Purdue University
Dept. of Physics, 1396 Physics Department, West Lafayette, IN, 47907 (35)[5]

P. Padley, M. Matveev, J. Roberts
Rice University
Dept. of Physics and Astronomy, Houston, Texas 77251 (36)[3]

Milind V. Purohit, Achim Weidemann
University of South Carolina
Dept. of Physics and Astronomy, Columbia, SC 29208 (37)[2]

Rachid Ayad, C. J. Martoff
Temple University
William Bugg, Steve Berridge, Yury Efremenko, Thomas Handler, Stefan Spanier, Yuri Kamyshkov
University of Tennessee
Dept. of Physics, Univ. of Tennessee, Knoxville, TN, 37996-1200 (39)[6..48..189]

Teruki Kamon
Texas A&M University
Dept. of Physics, Spence St., College Station, TX, 77843 (40)[1]

Andrew Brandt, Kaushik De, Shahnoor Habib, Venkat Kaushik, Jia Li, Mark Sosebee, Andy White, Jae Yu
University of Texas at Arlington
Dept. of Physics, Box 19059, High Energy Physics, UTA, Arlington, TX, 76019 (41)[8]

Karol Lang
University of Texas at Austin
Dept. of Physics, RLM 5.208, Austin, TX, 78712 (42)[1]

Nural Akchurin
Texas Technical University
Dept. of Physics, MS 1051, Lubbock, Texas 79409 (43)[1]

William P. Oliver
Tufts University
Dept. of Physics and Astronomy, Medford, MA, 02155 (44)[1]

S. Csorna¹, B. Feng², W. E. Gabella², John Kozub²
Vanderbilt University
Dept. of Physics and Astronomy¹, VU Station B 1807, Nashville, TN 37235
W. M. Keck Foundation Free-Electron Laser Center², 410 24th Avenue, Nashville, TN 37212 (45)[4]

Ivan Avrutsky, Rene Bellwied, Giovanni Bonvicini, David Cinabro, Mikhail Dubrovin, Alfredo Gutierrez, Paul Karchin, Vladimir Rykov, Alexander Schreiner
Wayne State University
Dept. of Physics, 666 W. Hancock, Detroit, MI, 48202 (46)[9]

Richard Prepost
University of Wisconsin-Madison
Dept. of Physics, 1150 University Ave., Madison, WI, 53706 (47)[1]
C. Baltay$^1$, W. Emmet$^1$, J. Hirshfield$^2$, H. Neal$^1$, D. Rabinowitz$^1$
Yale University
Dept. of Physics, Sloane Physics Lab$^1$, Beam Physics Laboratory$^2$
217 Prospect Street, PO Box 208120, New Haven, CT 06520-8120 (48)[5..31..220]

U.S. National Laboratories and Industries

Gary Drake, Wei Gai, John Power, José Repond, Dave Underwood, Barry Wicklund, Lei Xia
Argonne National Laboratory
9700 South Cass Avenue, Argonne, IL 60439 (1)[7]

Wei Chen$^2$, Vivek Jain$^1$, Francesco Lanni$^1$, Zheng Li$^2$, David Lissauer$^1$, Veljko Radeka$^2$
Brookhaven National Laboratory
Physics Dept.$^1$, Instrumentation Division$^2$, Upton, NY 11973 (2)[6]

Fermi National Accelerator Laboratory
PO Box 500, Batavia, IL, 60510 (3)[22]

Lars Ludeking, David Smithe
Mission Research Corporation, Santa Barbara, CA (4)[2]

Stanford Linear Accelerator Center
2575 Sand Hill Road, Menlo Park, CA, 94025 (5)[21..58]

Foreign Collaborating Institutions

Erhan Gulmez
Bogazici University
Dept. of Physics, Istanbul, Turkey (1)[1]
Gulsen Onengut  
Cukurova University  
Dept. of Physics, Adana, Turkey (2)[1]

Robert Rossmanith  
Forschungszentrum Karlsruhe, Germany (3)[1]

K. Kubo, A. Miyamoto, Toshiya Muto, Y. Sugimoto, Makoto Tobiyama, Junji Urakawa  
KEK, High Energy Accelerator Research Organization  
Tsukuba Science City, Japan (4)[6]

J.E. Augustin, M. Baubillier, M. Berggren, C. Carimalo, W. Da Silva, F. Kapusta, A. Savoy-Navarro  
LPHNE, Paris  
France (5)[7]

Ramazan Sever  
METU  
Dept. of Physics, Ankara, Turkey (6)[1]

J.Y. Huang  
PAL POSTECH  
Korea (7)[1]

C. Damerell  
Rutherford Appleton Laboratory  
Chilton, Didcot  
Oxon, UK  
OX11 0QX (8)[1]

Ryosuke Hamatsu, Pavel V. Karataev  
Tokyo Metropolitan University  
Dept. of Physics, Tokyo, Japan (9)[2]

Alexander P. Potylitsyn, Gennady A. Naumenko, Alexander S. Aryshev  
Tomsk Polytechnic University  
Russia (10)[3]

Aldo Penzo  
University of Trieste, INFN-Trieste  
Dept. of Physics, Trieste Italy (11)[1..25]
Table of Contents

Executive Summary ........................................................................................................ iii

Table of Contents ........................................................................................................ xiii

1. Introduction

Introduction ..................................................................................................................... 1.1

Physics Goals at the Linear Collider ......................................................................... 1.2

The Need for Detector and Accelerator R&D for the Linear Collider ................. 1.3

University Participation in Accelerator and Detector Research and Development .... 1.4

Structure of the Document and Coordination Between LCRD and UCLC .......... 1.6

2. Accelerator Physics

Table of Contents and Overview ................................................................................... 2.0

1. Beam Halo Monitor & Instrumented Collimators (LCRD; Lucien Cremaldi) .......... 2.1

2. Beam Test Proposal of an Optical Diffraction Radiation Beam Size Monitor at the SLAC FFTB (LCRD; Yasuo Fukui) ................................................................. 2.2

3. Design and Fabrication of a Radiation-Hard 500-MHz Digitizer Using Deep Submicron Technology (LCRD; K.K. Gan) ......................................................................... 2.3

4. RF Beam Position Monitors for Measuring Beam Position and Tilt (LCRD; Yury Kolomensky) ........................................................................................................... 2.4

5. Non-intercepting electron beam size diagnosis using diffraction radiation from a slit (UCLC; Bibo Feng) ......................................................................................... 2.5

6. Single-shot, electro-optic measurement of a picosecond electron bunch length (UCLC; Bill Gabella) ................................................................................................. 2.6

7. Fast Synchrotron Radiation Imaging System for Beam Size Monitoring (UCLC; Jim Alexander) ................................................................................................. 2.7
8. Radiation damage studies of materials and electronic devices using hadrons (LCRD; David Pellett) .................................................................................................................. 2.9

9. BACKGAMMON: A Scheme for Compton backscattered photoproduction at the Linear Collider (UCLC; S. Mtingwa) .................................................................................................................. 2.10

10. Ground Motion studies versus depth (LCRD; Mayda Velasco) ............................................. 2.11

11. Investigation of GAN Techniques in the Development and Operation of the TTF Data Acquisition System (UCLC; Don Hartill) .......................................................................................................................... 2.14

12. Investigation of acoustic localization of rf cavity breakdown (LCRD; George Gollin) ....................................................................................................................................... 2.15

13. RF Cavity Diagnostics and Acoustic Emission Tests (LCRD; Lucien Cremaldi) . 2.17

14. Control of Beam Loss in High-Repetition Rate High-Power PPM Klystrons (LCRD; Mark Hess).......................................................................................................................... 2.18

15. Research in Superconducting Radiofrequency Systems (UCLC; H. Padamsee) ...2.20

16. RF Breakdown Experiments at 34 Ghz (UCLC; J.L. Hirshfield)........................................... 2.21

17. Investigation of Novel Schemes for Injection/Extraction Kickers (LCRD; George Gollin) ........................................................................................................................... 2.22

18. Ring-tuned, permanent magnet-based Halbach quadrupole (LCRD; James Rosenzweig) ..................................................................................................................................... 2.23

19. Investigation and prototyping of fast kicker options for the TESLA damping rings (UCLC; Gerry Dugan) .......................................................................................................................... 2.25

20. Continuing Research and Development of Linac and Final Doublet Girder Movers (LCRD; David Warner) .......................................................................................................................... 2.26

21. Effects of Coherent Synchrotron Radiation in Linear Collider Systems (LCRD; James Ellison) ..................................................................................................................................... 2.27

22. Improved simulation codes and diagnostics for high-brightness electron beams (UCLC; Courtlandt L. Bohn) .................................................................................................................. 2.29

23. Beam simulation: main beam transport in the linacs and beam delivery systems, beam halo modeling and transport, and implementation as a diagnostic tool for commissioning and operation (UCLC; Dave Rubin) .......................................................................................................................... 2.30

24. Damping ring studies for the LC (UCLC; S. Mtingwa) ....................................................... 2.32
25. A Compact Wakefield Measurement Facility (LCRD; Young-Kee Kim) ............. 2.33

26. Experimental, simulation, and design studies for linear collider damping rings
   (UCLC; Joe Rogers) ..................................................................................................... 2.34

27. Undulator-Based Production of Polarized Positrons (LCRD; William Bugg) .... 2.37

28. Development of Polarized Photocathodes for the Linear Collider (LCRD; Richard Prepost) ............................................................................................................. 2.40

29. Transverse phase-space measurements for a magnetic bunch compressor by using
   phase-space tomography technique (LCRD; Feng Zhou) ............................................ 2.42

3. Luminosity, Energy, Polarization

Table of Contents and Overview .................................................................................... 3.0

30. An Explicitly Radiation-Hard Fast Gas Cerenkov Calorimeter for Bunch-by-Bunch
   Luminosity Measurement at the Next Linear Collider (LCRD; John Hauptman).......... 3.1

31. R&D for luminosity monitor (LCRD; Yasar Onel) .................................................. 3.2

32. Extraction line energy spectrometer (LCRD; Eric Torrence) ................................. 3.4

33. A Demonstration of the Electronic and Mechanical Stability of a BPM-Based Energy
   Spectrometer for an Electron-Positron Linear Collider (UCLC; Mike Hildreth)........... 3.5

34. Polarimetry at LC (LCRD; Yasar Onel) ................................................................ 3.6

35. Compton polarimeter backgrounds (LCRD; William Oliver) ............................... 3.7

36. Coherent and incoherent beamstrahlung at the LC (UCLC; Giovanni Bonvicini)... 3.8

37. Development of thin, fast, radiation hard, 3d-electrode array, silicon radiation sensors
   (LCRD; Sherwood Parker) ............................................................................................ 3.9

38. Polarimeter with a Quartz Fiber Calorimeter (LCRD; Stefan Spanier)............... 3.10
4. Vertex Detector

Table of Contents and Overview ................................................................................................. 4.0

39. Pixel Vertex Detector R&D for Future High Energy Linear e+ e- Colliders (LCRD; Charlie Baltay) ................................................................................................................ 4.1

40. Development and design of an LC ASIC for CCD readout and data reduction (UCLC; Patrick Skubic) ................................................................................................................ 4.2

41. Study of the Mechanical Behavior of Thin silicon and the Development of hybrid silicon pixels for the LC (UCLC; Daniella Bortoletto) ................................................................. 4.3

5. Tracking

Table of Contents and Overview ................................................................................................. 5.0

42. Development and Evaluation of Forward Tracking in the Linear Collider (LCRD; Michael Strauss) ...................................................................................................................... 5.1

43. Development of a GEM based Forward Tracking Prototype for the NLC (LCRD; Lee Sawyer) .................................................................................................................................. 5.2

44. Straw Tube Wire Chambers for Forward Tracking in the Linear Collider Detector (UCLC; Keith Baker) .............................................................................................................. 5.3

45. Fabrication, investigation and simulation of Gas Electron Multipliers for charged particle tracking (LCRD; Peter Fisher) .............................................................................................. 5.4

46. Studies of the Use of Scintillating Fibers for an Intermediate Tracker which Provides Precise Timing and Bunch Identification: Progress Report and Request For Funds (LCRD; Rick VanKooten) ......................................................................................................... 5.5

47. Tracking Detector R&D at Cornell and Purdue Universities (UCLC; Dan Peterson) .................................................................................................................................................. 5.7

48. Tracking simulation studies and alignment system R&D (UCLC; Keith Riles) .................................................................................................................. 5.8

49. Tracking Software Optimization for the Silicon Detector Option (LCRD; Milind Purohit) ................................................................................................................................. 5.9
6. Calorimetry

Table of Contents and Overview .......................................................................................... 6.0

53. Design and Prototyping of a Scintillator-based Digital Hadron Calorimeter (UCLC; Vishnu Zutshi) .................................................................................................................. 6.1

54. Linear Collider Detector Development Proposal to Develop Scintillator-Fiber Readout Calorimetry with a Novel Geometrical Design that has Excellent Spacial Resolution (LCRD; Uriel Nauenberg) .................................................................................................................. 6.2

55. Fast Response Tile Scintillation Development for Calorimetry and Tracking in NLC Detectors (UCLC; Mike Hildreth) ........................................................................................................... 6.3

56. Energy Flow Studies with the Small Detector at the Linear Collider (LCRD; Usha Mallik) ........................................................................................................................................... 6.4

57. Development of a silicon-tungsten test module for an electromagnetic calorimeter (LCRD; Raymond Frey) .................................................................................................................. 6.5

58. Digital Hadron Calorimetry for the Linear Collider using GEM based Technology (LCRD; Andy White) ......................................................................................................................... 6.6

59. Development of energy-flow algorithms, simulation, and other software for the LC detector (UCLC; Dhiman Chakraborty) ........................................................................................................ 6.9

60. Investigation and Design Optimization of a Compact Sampling Electro-magnetic Calorimeter with High Spatial, Timing and Energy Resolution (UCLC; Graham Wilson) .................................................................................................................. 6.10

61. RPC Studies and Optimization of LC detector elements for physics analysis (UCLC; Mark Oreglia) ........................................................................................................................................ 6.11

63. Cherenkov compensated calorimetry (LCRD; Yasar Onel) .............................................. 6.13

64. Study of Resistive Plate Chambers as Active Medium for the HCAL (LCRD; José Repond) ................................................................................................................................. 6.14

65. Proposal for Design Study of Active Mask for Future Linear Collider (LCRD; Teruki Kamon) ................................................................................................................................. 6.15

7. Muon System and Particle Identification

Table of Contents and Overview ............................................................................................. 7.0

66. Scintillator Based Muon System R&D 2004-2007 (LCRD; Paul Karchin) ................. 7.2

67. Scintillator Based Muon System R&D (UCLC; Mitchell Wayne)..................................... 7.3

68. Demonstration of Geiger Mode Avalanche Photodiodes for Linear Collider Muon System Readout (LCRD; Robert Wilson) ................................................................................. 7.5

Appendices and References

Appendix 1: Participation data and indices ........................................................................ 8.1

Appendix 2: Linear Collider Detector R&D ......................................................................... 8.2

References ............................................................................................................................. 9.1
Introduction

A worldwide consensus that the next large facility in particle physics should be an international high energy electron-positron collider has emerged in the last two years. The strong recommendation from the U.S. High Energy Physics Advisory Panel that a high energy, high-luminosity, electron-positron linear 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, as well as the maturity of accelerator designs being simultaneously advanced (and proposed) at laboratories in the United States, Germany, and Japan, and the necessity for international cooperation.

Response to this consensus has been swift. Regional Steering Committees, charged with organizing and coordinating Linear Collider activities in Asia, Europe, and the Americas, have been formed, as has their international counterpart, the International Linear Collider Steering Committee. Under the auspices of the ILCSC, technical reviews of the two competing collider technologies have been completed, and recently an International Technology Recommendation Panel has been constituted and charged with choosing the technology for collider construction. At the national level, the U.S. Department of Energy has just announced inclusion of the Linear Collider in its 20 year plan for new facilities, according it highest priority among the mid-term projects under consideration.

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 understanding fruitful directions for research and collaboration towards the Linear Collider. The hundreds of technical issues involved in the design and construction of the accelerator and detector emerged as an organizing theme. The University Consortium for Linear Collider R&D (UCLC) organized itself to consider these issues in the context of NSF support, and the Linear Collider Research and Development Working Group (LCRD) did likewise in the context of DOE support. The two groups are naturally intermingled with each other, and with the preexisting American Linear Collider Physics Group (ALCPG). All concerned are working together to coordinate their activities to the single task of building the linear collider.

The result was the production of a joint UCLC/LCRD document, *A University Program of Accelerator and Detector Research for the Linear Collider*, which collected the combined NSF and DOE proposals into a single program for LC related R&D. The Working Groups of the American Linear Collider Physics Group provided guidance, coordination, and advice to the individual proponents of both detector and accelerator R&D. They were joined by an ad hoc Accelerator Working Group which did the same for the accelerator proposals. In all, 71 proposals were collected from 47 U.S. universities, which addressed the full range of detector and machine(detector interface concerns, and complemented existing accelerator R&D efforts. A group of UCLC and LCRD organizers assembled a coherent document which was submitted for rigorous review to separate Detector and Accelerator Review Panels which met at Fermilab in
September, 2002. After allowing for minor changes in the sub-proposals in response to comments from the reviewers, the UCLC /LCRD organizers assembled the final document on October, 22, 2002, and then formally submitted it to the NSF and DOE. DOE funded the highest ranked detector R&D sub-proposals in March, 2003, and, after further internal review, the chosen accelerator proposals in May. Roughly $400k was allotted to each of detector and accelerator R&D. The NSF began funding the UCLC consortium with $150k in late Spring, with the understanding that the full proposal should be resubmitted for reconsideration early in the FY04 budget process.

This document, Volume II of A University Program of Accelerator and Detector Research for the Linear Collider, presents the continuation of the Linear Collider R&D proposal process for FY04. As in year one, it includes a nationally coordinated program of university based linear collider research reaching across both funding agencies. Forty-eight U.S. universities from 25 states, working with five national and industrial labs and eleven foreign institutions, offer 68 proposals in a broad coverage of the previously identified R&D needs of the linear collider. Accelerator R&D maintains the prominent role it took in Volume I.

The fiscal facts of life have differentiated the DOE and NSF proposal processes somewhat more this year, with the UCLC umbrella proposal having been submitted to NSF already during Summer, 2003 in order to take full advantage of the FY04 funding cycle. The UCLC proposals are included in the present document, however, so that an accurate representation of the entire American effort in University based Linear Collider R&D emerges. Again the Working Group leaders of the ALCPG, in concert with the LCRD group, have offered constructive criticism to the proponents. In contrast to its first year, the Program for Linear Collider R&D is this year not strictly a University enterprise, with proposals welcomed from Argonne, Brookhaven, and LBNL. DOE requested that present proposals consider a three-year horizon, assuming that funding will remain roughly constant over that time. Within this time frame, key detector and accelerator R&D issues critical to the success of the Linear Collider will be addressed, and a growing community of high energy physicists will be initiated into the study of physics at the Linear Collider.

**Physics Goals at the Linear Collider**

The physics goals of the Linear Collider are ambitious and compelling. The Linear Collider is needed to address the central issue in particle physics today, the origin of mass and electroweak symmetry breaking. Over the past decade, a wide variety of experiments has shown that elementary particle interactions at the TeV scale are dictated by an $SU(3) \times SU(2) \times U(1)$ gauge symmetry. The non-zero masses of the $W$ and $Z$ particles imply, however, that the electroweak $SU(2) \times U(1)$ symmetry is broken spontaneously. We do not know how the symmetry is broken, and we will not know until the agents of electroweak symmetry 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 Linear Collider.
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, $m_H \leq 200$ GeV. However, we know this model does not work well 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 Linear Collider.

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 (LC) 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 LC can determine the lightest superpartners' masses with exquisite precision. Since the LHC measures mass differences more precisely than the masses themselves, one sees that a single LC measurement will significantly improve and extend the whole program of SUSY measurements at the LHC. In both these cases, the Linear Collider adds critical information to what will be learned at LHC. The Linear Collider 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 Linear Collider can be found in the Resource Book prepared for Snowmass 2001 or the physics chapter of the Tesla Technical Design Report. 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 device can be built in a timely and cost-effective fashion.

The Need for Detector and Accelerator R&D for the Linear Collider

The physics goals of the Linear Collider require a starting energy of 500 GeV, upgradeable to 1 TeV or more and a luminosity of about $2 \times 10^{34}$ cm$^{-2}$ s$^{-1}$, an ambitious four orders of magnitude larger than the luminosity achieved by the first linear collider, the SLC. Achieving the high energy and ultra-low emittance of the Linear Collider requires significant advances in accelerator physics and technology: end-to-end simulation of the entire accelerator complex; mastery of the consequences of strong
wakes; ultra-fast beam manipulation; nanometer stability of the beams at the crossing point; extreme stability in beam energy, luminosity and polarization; handling unprecedented beam power; and the development of instrumentation to monitor the beam on a bunch-by-bunch basis. A construction start in 2009 requires that the basic R&D required for a full technical design be complete by 2006. Much R&D remains to be done, and is urgently needed. The International Linear Collider Technical Review Committee concluded its 2003 report with a list of high priority R&D items in the areas of: accelerator simulation and design; accelerator experiments; the development and test of radio-frequency systems, instrumentation, and other hardware; and operational issues.

To exploit the full physics potential of a 500 GeV Linear Collider, the detector must move well beyond the designs of the LEP/SLC era, and beyond the current state of the art. The detector development which has gone on in preparation for the LHC experiments has certainly advanced the art, particularly in terms of extreme rate capability and radiation hardness, and also in terms of dealing with the TeV energy scale in tracking and calorimetry. But it has not pushed detector performance to the level required for high precision measurements at the LC, or to the level allowed by the very different experimental environment found at the LC: low event rates, a relatively benign radiation field, and events clean from the debris of the underlying event or multiple interactions.

R&D is required for each of the major detector subsystems. High performance vertex detection is a necessity at the LC, to extract the full precision from measurements of the Higgs branching fractions into $b$ quarks, $c$ quarks, and gluons. Development is needed to boost CCD readout speeds and radiation hardness and/or to develop fast, thin, high resolution alternatives. Very high momentum resolution in the tracking detector, which will permit the Higgs to be tagged in recoil with a Z, will require new readout techniques and improved spatial resolution in the TPC, or precision alignment in a silicon tracker. Further studies are needed to guarantee full coverage in the forward region, to study backgrounds and thinning requirements and evaluate pattern recognition capabilities for different designs. LC calorimeters must distinguish W and Z bosons, and improve energy resolution by a factor of two over today’s designs. Energy flow calorimetry must be fully simulated and detector parameters optimized. Since lepton ID involves the interplay of the tracking detector and both the electromagnetic and hadronic calorimeters, overall system performance must be evaluated and optimized. The case for hadron ID, besides its obvious application for quark flavor tagging in Giga-Z running, hasn’t yet been made, so it needs further study. Precision threshold measurements will depend on a determination of the machine energy to an accuracy well beyond what has been so far achieved and precise knowledge of the differential luminosity spectrum, a new variable at colliders.

**University Participation in Accelerator and Detector Research and Development**

The community of High Energy Physics experimentalists, as well as other members of the scientific community, can bring expertise and a fresh perspective to many of these problems. The engagement of HEP experimentalists in accelerator physics has often played an important role in the development of new accelerator technologies, and was an essential part of the development of the SLC. The machine/detector interface grew less
distinct as particle physicists learned to measure beam sizes from deflection scans and beam energies with synchrotron light, and came to play a significant role in developing accelerator controls and instrumentation, fast kicker magnets, and beamstrahlung monitors. Many of the most fundamental experimental challenges in studying high energy $e^+e^-$ collisions reside with the accelerator, so it is natural to direct part of the intellectual resources of the HEP community in this direction.

The design, construction, and utilization of the Linear Collider offers profound opportunity for the engagement of university based physics and engineering groups, and will pay back large dividends of intellectual stimulation and scientific discovery.

The LCRD/UCLC proposal marks a fundamental change in the level of engagement of U.S. universities in the Linear Collider (LC). In the year 2001, LC work was supported at fifteen U.S. universities, and the work was largely confined to physics and detector simulation studies. Almost all of the accelerator related work was performed at national laboratories. In this proposal, the number of institutions has increased by almost a factor of four, with most participants having had no prior affiliation with the any LC effort. The detector sub-proposals request support to move beyond simulation, into prototyping of real devices. In a significant broadening of focus, nearly half of the sub-proposals are for work on accelerator issues. The increase in numbers and breadth of focus follows on the Snowmass consensus, and the excitement and commitment of the U.S. university physics community toward making the Linear Collider a reality.

One of the organizing principles of this proposal is that the task of designing and building the collider and detectors contains, a priori, hundreds of research and development issues that are excellent fits to the mission and resources of university physics and engineering groups. Although critical path issues are already under investigation at the major laboratories, many important technical issues remain unaddressed and unresolved. Solutions to these problems will yield essential instrumentation for the Linear Collider, reduce its cost, increase its reliability, and contribute to the selection of optimal technologies. University–laboratory collaborations will disseminate knowledge of the issues, bring fresh perspectives, and perhaps lead to breakthroughs.

The study and control of dense beams of electrons requires a scientific and engineering infrastructure that starts in electrodynamics and beam physics, but spills into many other fields, including lasers, optics, interferometry, motion stabilization, superconductivity, materials science, acoustics, plasma physics, microwaves, and power and control systems. Problems in these areas are ideal foci for interdisciplinary collaborations with other university departments beyond physics, which can build a support base for the Linear Collider, and fulfill its potential as a broad stimulant for all science and technology. Some of this collaboration-across-boundaries has already been realized in the research projects presented here, and we expect to see more of it arise as the work progresses.

We wish to stress that universities bring a very important resource to any research and development program: students. In engaging our graduates and undergraduates, we serve to train the next generation of scientists and engineers in all of the fields described above.
Our students participate as more than just a skilled and enthusiastic labor pool: when the facility is operating, many of these student “builders” will have become members of the next generation of high energy physicists. Their research will be conducted simultaneously at the Collider facility and in the academic departments of every collaborating institution, carrying forth the excitement and stimulation of science and technology into the larger community.

**Structure of the Document and Coordination Between LCRD and UCLC**

This document has been written in collaboration by members of LCRD and UCLC, and describes the combined set of research projects that members of both groups are planning to pursue. We have found it most natural to organize the research around the topics to be studied, and this is reflected in the order in which projects appear in the body of *A University Program of Accelerator and Detector Research for the Linear Collider*.

The material is divided into sections covering accelerator physics and technology; luminosity, energy, and polarization measurements; vertex detectors; tracking detectors; calorimetry; muon and particle identification systems. Each section begins with a table of contents and an overview of the planned investigations, followed by descriptions of the R&D projects written by the participating groups. Appendices at the end of the document provide additional information about the level of total funding requested and the geographical distribution of the participants.

One of our concerns was to develop an effective set of projects with easy collaboration across the boundaries of geography and funding agency in order to avoid unnecessary, and inefficient duplication of effort. We have been aided greatly in this by the ALCPG and its working group leaders, capably led by Jim Brau and Mark Oreglia. To balance the ALCPG’s focus on detector issues, Tom Himel, Joe Rogers, and Dave Finley formed The American Working Group on Linear Collider Accelerator Technology in order to play a similar role in the accelerator physics sphere. They have all done us a significant service, reviewing early versions of project descriptions to suggest cooperation between groups, changes of focus, and adjustment of priorities. We have found that the combination of shared goals, common sense, and the excitement of beginning something new have made the process go more smoothly than anticipated.

The U.S. Linear Collider Steering Group, chaired by Jonathan Dorfan, has played a significant role in coordinating the review and submission process for the proposals. After negotiating a sensible timeline and review process with the funding agencies and participants, the Steering Group assembled the review panels, received their reports, and provided guidance on the dissemination of results to proponents. The Steering Group continues to provide guidance concerning direction and organization to both UCLC and LCRD.

Budgets shown in this document are expected to reflect accurately the ultimate budgets submitted to the funding agencies. For UCLC project descriptions the budget tables are identical to those used to generate the UCLC proposal transmitted to NSF. However,
LCRD subproposal budgets have not yet been reviewed by the various offices of sponsored research at the proponents' home institutions. It is possible that further scrutiny of the algorithms governing calculation of indirect costs will necessitate minor corrections to some of the LCRD subproposal budgets.

The landscape is evolving rapidly. The HEPAP recommendation concerning the Linear Collider was released in January, 2002. Nine months later, after workshops at Chicago, Fermilab, Cornell, SLAC, and Santa Cruz, the physics community in the United States generated a set of 71 research proposals to participate in the realization of a new machine. These proposals were submitted for funding last year; the present document contains descriptions of the outcome of the year's work and proposals for extensions to what has already been accomplished. It is an exciting time.

The greatest part of the work associated with the generation of the proposals has come from the participating groups. The organizers (from both LCRD and UCLC) who have been working to smooth the way for the proponents are listed below.

- Dan Amidei (Michigan: amidei@umich.edu)
- Dhiman Chakraborty (Northern Illinois: dhiman@fnal.gov)
- Dave Cinabro (Wayne State: cinabro@physics.wayne.edu)
- Gerry Dugan (Cornell: gfd1@cornell.edu)
- Dave Finley (Fermilab: finley@fnal.gov)
- George Gollin (Illinois: g-gollin@uiuc.edu)
- Tom Himel (SLAC: thimel@slac.stanford.edu)
- John Jaros (SLAC: john@slac.stanford.edu)
- Usha Mallik (Iowa: usha-mallik@uiowa.edu)
- Ritchie Patterson (Cornell: ritchie@lns.cornell.edu)
- Joe Rogers (Cornell: jtr1@cornell.edu)
- Slawek Tkaczyk (Fermilab: tka@fnal.gov)