Chapter 1 Introduction

The American particle physics community can look forward to a well- conceived and vital program of experimentation for the next ten years, using both colliders and fixed target beams to study a wide variety of pressing questions. Beyond 2010, these programs will be reaching the end of their expected lives. The CERN LHC will provide an experimental program of the first importance. But beyond the LHC, the American community needs a coherent plan. The Snowmass 2001 Workshop and the deliberations of the HEPAP subpanel offer a rare opportunity to engage the full community in planning our future for the next decade or more.

A major accelerator project requires a decade from the beginning of an engineering design to the receipt of the first data. So it is now time to decide whether to begin a new accelerator project that will operate in the years soon after 2010. We believe that the world high-energy physics community needs such a project. With the great promise of discovery in physics at the next energy scale, and with the opportunity for the uncovering of profound insights, we cannot allow our field to contract to a single experimental program at a single laboratory in the world.

We believe that an e^+e^- linear collider is an excellent choice for the next major project in high-energy physics. Applying experimental techniques very different from those used at hadron colliders, an e^+e^- linear collider will allow us to build on the discoveries made at the Tevatron and the LHC, and to add a level of precision and clarity that will be necessary to understand the physics of the next energy scale. It is not necessary to anticipate specific results from the hadron collider programs to argue for constructing an e^+e^- linear collider; in any scenario that is now discussed, physics will benefit from the new information that e^+e^- experiments can provide.

This last point merits further emphasis. If a new accelerator could be designed and built in a few years, it would make sense to wait for the results of each accelerator before planning the next one. Thus, we would wait for the results from the Tevatron before planning the LHC experiments, and wait for the LHC before planning any later stage. In reality accelerators require a long time to construct, and they require such specialized resources and human talent that delay can cripple what would be promising opportunities. In any event, we believe that the case for the linear collider is so compelling and robust that we can justify this facility on the basis of our current knowledge, even before the Tevatron and LHC experiments are done.

The physics prospects for the linear collider have been studied intensively for more than a decade, and arguments for the importance of its experimental program have been developed from many different points of view. This book provides an introduction and a guide to this literature. We hope that it will allow physicists new to the consideration of linear collider physics to start from their own personal perspectives and develop their own assessments of the opportunities afforded by a linear collider.

The materials in this book are organized as follows. In Chapter 2, we reprint the 'Linear Collider Whitepaper', a document prepared last summer by the linear collider supporters for the Gilman writing group of HEPAP [1]. This document presents a distilled argument for the first phase of the linear collider at 500 GeV in the center of mass. Though it describes a number of physics scenarios, it emphasizes a particular perspective on the physics to be expected at the next scale. Considerable space is given to the analysis of a light Higgs boson—as called for by the precision electroweak measurements—and to measurements of supersymmetry, motivated, for example, by the precisely known values of the Standard Model coupling constants. There is no question that, in these scenarios, the linear collider would provide a program of beautiful and illuminating experiments.

The 'Sourcebook for LC Physics', Chapters 3–8 gives a more complete overview of the physics measurements proposed for the linear collider program. In separate sections, we review the literature that describes the measurements that the linear collider will make available on the full variety of physics topics: Higgs, supersymmetry, other models of the electroweak symmetry breaking (including new Z bosons, exotic particles, and extra dimensions), top quark physics, QCD, and the new precision electroweak physics available at linear colliders. The chapter on Higgs physics includes a thorough review of the capabilities of a linear collider for the study of the Standard Model Higgs boson as a function of its mass.

Chapter 9 gives a survey of theoretical approaches to the next scale in physics and the implications of each for the linear collider physics case. This chapter attempts to cover the full range of possibilities for physics at the next energy scale. We hope that this review will be useful in putting each particular physics scenario into a larger perspective.

The discussion of experimental program issues in Chapters 10–14 presents a number of options for the linear collider experimental program, weighing their merits and requirements. We begin by presenting some typical scenarios for operation of the linear collider, with suggested choices for energy and luminosity to meet specific physics goals. We then discuss the baseline experimental facilities. Our baseline design is an accelerator of 500 GeV center-of-mass energy, with polarized e^- beams, and with two interaction regions that share the luminosity. The design envisions a number of upgrade paths. These include low-energy precision measurements in one of the two regions and e^+e^- collisions at multi-TeV energies in the other. The logic of these plans is described in some detail. In the subsequent chapters, we discuss the possible options of positron polarization, operation of a $\gamma\gamma$ collider by laser backscattering from electron beams, and operation for e^-e^- collisions. In each case, we review the promise and the technological problems of the approach.

Chapter 15 discusses detectors for the linear collider experiments. We present and cost three detector models. We also discuss issues for the linear collider detector design. Though a generic LEP-style detector could carry out the basic measurements, the linear collider environment offers the opportunity for exceptional detection efficiencies and precision in the study of physics processes. We list a number of research problems whose solution would allow us to realize the full potential that high energy e^+e^- collisions offer.

The final chapter gives a list of suggested questions that could be taken up at Snowmass or in other studies. Many of these arise from the specific discussions of the earlier chapters. They range from questions of accelerator and detector optimizations to physics issues that require first study or more careful scrutiny.

We do not discuss linear collider accelerator designs in this book, but a number of useful reports on the various current proposals are available. TESLA, based on superconducting rf cavities, has been submitted to the German goverment as a formal TDR [2]. A detailed proposal for the warm cavity accelerator developed by the NLC and JLC groups was presented in the 1996 ZDR [3], and the current NLC baseline is described in a separate paper for the Snowmass 2001 workshop [4]. These two approaches have different emphases and differ in many details. However, both designs meet the requirements to achieve the physics goals that we discuss in this book.

We believe that it is urgent that the American high-energy physics community come to grips now with the issues related to the linear collider. There are several reasons for this. First, the proposals for a linear collider in Europe and in Asia are now becoming explicit. Inevitably, such proposals will raise the question of how the American community will participate. We are approaching the time when the nature of our involvement will be decided by default, not by our design. Second, the high energy frontier of accelerator-based research will pass to the LHC in only a few years. Since the health of any region's particle physics community depends on its central participation in a frontier facility, the US community needs to address how it will participate in the major facilities of the coming era. Third—and most importantly—the linear collider is very likely, in our opinion, to make major progress on the most pressing physics questions before us today. We can offer no guarantee of this, since it is the nature of our field that each new frontier accelerator steps into the unknown. But for all the ways that are foreseen to resolve the mystery of the origin of electroweak symmetry breaking, measurements at the linear collider would be of crucial importance.

References

[1] J. Bagger *et al.* [American Linear Collider Working Group], hep-ex/0007022.

[2] TESLA Technical Design Report, `http://tesla.desy.de/new_pages/TDR_CD/start.html`.

[3] NLC Zeroth-Order Design Report, SLAC-R-474, `http://www.slac.stanford.edu/accel/nlc/zdr/`.

[4] US NLC Collaboration, *2001 Report on the Next Linear Collider*, FERMILAB–Conf–01/075–E, LBNL–47935, SLAC–R–571.