Questions for Further Study

Chapter 16 Suggested Study Questions on LC Physics and Experimentation

1 Physics issues

1.1 Higgs physics

For further information on this section, consult with: Jack Gunion, Howard Haber, Andreas Kronfeld, Rick van Kooten.

1. Perform a fully simulated study of the precision to which Higgs branching ratios can be determined for $m_h = 115$ GeV; for $m_h = 140$ GeV; for $m_h = 200$ GeV. How do these precisions depend on CM energy?

2. Is $\gamma\gamma$ needed to measure the total Higgs width, for low mass Higgs?

3. Outline the necessary experimental program to determine the spin/parity of a putative Higgs state.

4. Optimize a program for determination of the Higgs self-couplings. What requirements does this study impose on the dijet invariant mass resolution?

5. What is the utility of positron polarization for Higgs measurements?

6. From knowledge of measured Higgs branching ratios (fermion pairs, ZZ, WW, gg, $\gamma\gamma$), the total width, and the couplings g_{ZZh}, g_{WWh}, what reach is available to detect the presence of the SUSY states H, A? What is the relative importance of errors in each measurement?

7. To what extent can one measure $\tan\beta$ for the SUSY Higgs from Higgs sector measurements alone? Is it possible to do so in a truly model-independent way for the most general sets of MSSM parameters?

8. How will one disentangle H^0 and A^0 in the decoupling limit where the masses are nearly degenerate?

9. Contrast the use of e^+e^- and e^-e^- beams for the $\gamma\gamma \to h$ measurement. The use of e^+e^- admits numerous physics backgrounds that are absent for e^-e^-. Is it critical to avoid these backgrounds? Can the advantage of e^-e^- over e^+e^- be compensated by higher integrated luminosity?

10. The dominant backgrounds to $\gamma\gamma \to h \to b\bar{b}$ are $\gamma\gamma \to b\bar{b}(g)$ and $\gamma\gamma \to c\bar{c}(g)$. The production cross section for $c\bar{c}(g)$ is about 25 times larger than for $b\bar{b}(g)$. The background can be suppressed, first, by improved b tagging, and second, by improved Higgs (two-jet) mass resolution. With this in mind, what is the optimal strategy for isolating the Higgs peak from the background?

11. Contrast the use of e^+e^- and e^-e^- beams, in the same way, for a broadband search for a heavy Higgs s-channel resonance in $\gamma\gamma$.

1.2 Supersymmetry

For further information on this section, consult with: Jonathan Feng, Uriel Nauenberg, Frank Paige, James Wells.

1. Develop a plan for measuring the chargino mass matrix, including mixing, for the most general sets of MSSM parameters.

2. Do the same for the neutralino, stau and stop mixing matrices.

3. Is there a program by which one could, at least in principle, measure all 105 independent MSSM parameters?

4. What can LC measurements tell us, and with what precision, about the nature of the SUSY model and the SUSY breaking mechanism and scale? What can be learned about the scale and physics of grand unification?

5. Evaluate the benefit of positron polarization for SUSY measurements.

6. For what questions of SUSY spectroscopy are $\gamma\gamma$, $e\gamma$, and e^-e^- beams of special importance?

7. How well can CP-violating effects be studied in supersymmetry? How do these compare and connect to those made in the B factories or K decays?

8. What limits can be set on lepton flavor violation in slepton reactions? Is it possible to measure quark flavor violation effects that are associated with SUSY parameters and independent of CKM mixing?

9. What measurements from the LC would be required to verify the neutralino origin of cosmological dark matter?

10. What information encoded in the SUSY parameters can provide information about the nature of string/M theory?

1.3 New physics at the TeV scale

For further information on this section, consult with: Tim Barklow, Bogdan Dobrescu, JoAnne Hewett, Slawek Tkaczyk.

1. What precision can eventually be reached on anomalous WWV, ZZV and $t\bar{t}V$ couplings? What machine parameters are needed?
2. For the broad range of strong coupling models that obey existing precision EW constraints, what are the observable consequences at a 500 GeV LC? At 1000 GeV? At 1500 GeV? Are there models of strong coupling for which there are no observable consequences at 500 GeV?
3. Is it possible for models of a strong-coupling Higgs sector to mimic predictions of supersymmetry or extended Higgs models in a way that these models cannot be distinguished at the LHC? What e^+e^- measurements would be most important in these cases?
4. What is the utility of $\gamma\gamma$ or e^-e^- operation for probing the strong coupling models?
5. Develop general classification of models with large extra dimensions.
6. How can measurements at the TeV scale constrain string/M-theory models with string or quantum gravity scales much less than 10^{19} GeV?
7. Describe the reach of a LC for seeing large extra dimensions as a function of energy and luminosity in various scenarios. To what extent does the higher precision of a 500 GeV LC complement the higher energy reach of the LHC?
8. What is the role of $\gamma\gamma$, $e\gamma$, and e^-e^- experiments in probing models with extra dimensions?
9. What would be the role of the LC in understanding the nature of cosmological dark matter in models not related to supersymmetry?
10. In what way can LC measurements constrain gravitational effects such as Hawking black hole radiation?

1.4 Top quark physics

For further information on this section, consult with: Ulrich Baur, David Gerdes.

1. How well can the top quark width be determined from threshold measurements? A full analysis should include the threshold shape, the top quark momentum distribution, and the forward-backward asymmetry from S–P mixing. Are there additional effects that can contribute to this determination?

2. Can one determine the top quark Yukawa coupling at the $t\bar{t}$ threshold? With what precision?

3. Can CP violation associated with the top quark be probed at the $t\bar{t}$ threshold?

4. Can a high-precision top quark mass be obtained from continuum $t\bar{t}$ production? Is there an infrared-safe definition of m_t that can be applied to this analysis?

5. How well can the top quark Yukawa coupling be determined in $e^+e^- \to t\bar{t}h$? What backgrounds arise from other top quark production processes (*e.g.*, $e^+e^- \to t\bar{t}g$)? Are spin correlations derived from kinematic fitting useful in this analysis?

6. How well can one measure the vector and axial $t\bar{t}Z$ couplings?

7. How well can one measure the $t\bar{t}\gamma$ form factors and the top anomalous magnetic moment?

8. How well can one measure the $(V + A)$ decay of the top quark?

9. What ambiguities arise when one fits for more than one anomalous coupling at a time? Can polarization or spin correlation measurements resolve these ambiguities?

1.5 QCD and two-photon physics

For further information on this section, consult with: Bruce Schumm, Lynne Orr.

1. What is the precision that can be obtained for α_s from e^+e^- annihilation? In particular, can it be definitively demonstrated that detector systematics are less than $\pm 1\%$?

2. What is the precision that can be obtained for α_s from measurements on the top quark?

3. Outline the program for obtaining the photon structure functions. What energies of operation are desired, and are special beam conditions required?

4. How can the LC make definitive studies of all-orders BFKL resummation?

1.6 Precision electroweak measurements

For further information on this section, consult with: Lawrence Gibbons, Bill Marciano.

1. Evaluate the need for Giga-Z in various scenarios in which there do or do not exist light Higgs particles.

2. Evaluate the need for Giga-Z in scenarios in which new light particles from supersymmetry or other new physics are discovered.

3. Are there strategies for further improving the precision for measuring $\sin^2\theta_w$ using Z-pole observables? How can the various systematics limits described in the text be avoided?

4. Evaluate the precision of W and top quark mass measurements. What special measurements of the accelerator parameters will be needed to achieve this precision?

5. What are the systematic limits on B physics measurements, including CKM parameters and rare B decay rates, at a polarized Z factory?

2 Accelerator issues

2.1 Running scenarios

For further information on this section, consult with: Joel Butler, Paul Grannis, Michael Peskin.

1. What elements should be present in a charge to a future international technical panel established to compare linear collider technical proposals? What emphasis should be given to risk analysis, needed R&D, upgradability in energy or luminosity, cost comparison?

2. For a physics-rich scenario (*e.g.*, low mass Higgs and SUSY with observable $\widetilde{\chi}_1^0$, $\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^+$, $\widetilde{t}$, $\widetilde{\tau}$) outline the desired run plan, giving the required integrated luminosity for all necessary beam energies, beam polarizations, beam particles. What compromises can be envisioned to limit the number of distinct machine parameters without undue effect on the physics results?

3. Do the same for a thinner physics scenario (*e.g.*, with Higgs mass of 180 GeV and no supersymmetry or other new particle observation).

2.2 Machine configuration

For further information on this section, consult with: Charles Prescott, Tor Raubenheimer, Andre Turcot.

1. Evaluate an IR scheme with IR1 capable of operation at $E_{CM} \leq 250$ GeV and IR2 capable of operation at $E_{CM} < 500$ (1000) GeV. Contrast this configuration with one in which two detectors share an IR in push-pull mode.

2. How important is it that the LEIR be able to operate at energies of 500 GeV or higher?

3. Evaluate the benefits from simultaneous operations at two IRs (with interleaved pulse trains). What are the constraints on the collider design?

4. What are the requirements imposed on the first-phase accelerator design to permit upgrade to multi-TeV energies?

5. What constraints and opportunities are brought by including a free electron laser facility with the NLC? Are there other non-HEP uses of the linear accelerator that could be contemplated?

2.3 Positron polarization

For further information on this section, consult with: John Jaros, Steve Mrenna, Mike Woods.

1. Evaluate the need for positron polarization in accomplishing the physics program. What polarization (and error), energy (and error), luminosity are required for the relevant physics topics?

2.4 Photon collider

For further information on this section, consult with: Jeff Gronberg, Adam Para, Tom Rizzo, Karl van Bibber.

1. Compile the list of physics topics for which $\gamma\gamma$ operation is essential or desirable.

2. Typically $\gamma\gamma$ luminosity and $e\gamma$ luminosity are comparable at a $\gamma\gamma$ collider. Identify $e\gamma$ processes that might be problematic backgrounds for $\gamma\gamma$ physics analyses.

3. How can a detector be made compatible with both $\gamma\gamma$ and e^+e^- operation?

4. Is it sufficient to provide $\gamma\gamma$ collisions only for $E_{CM}(\gamma\gamma) < 400$ GeV (*i.e.*, at the low energy IR)?

5. Evaluate the prospects for high-power lasers and the configuration of the $\gamma\gamma$ IR. Is R&D needed on the most important IR components (*e.g.*, mirrors, masking, beam stability)?

2.5 e^-e^-

For further information on this section, consult with: Jonathan Feng, Clem Heusch.

1. Compile the list of physics topics for which e^-e^- operation is essential or desirable.

2.6 Fixed Target

For further information on this section, consult with: Mike Woods.

1. What experiments could be done using the e^- or e^+ beam of a linear collider for fixed target experiments? For example, can Møller scattering of a fixed target beam be used to obtain $\sin^2\theta_w$ with very high precision? Can the spent beams that have passed through the interaction region be used in these experiments?

2. What are the relative advantages of e^- *vs.* e^+ beams?

3. What experiments could be done using the polarized γ beams from laser backscattering for fixed target experiments? Can fixed target experiments be done with the spent beams while the collider is operating in $\gamma\gamma$ mode?

3 Detector issues

3.1 Detectors

For further information on this section, consult with: Jim Brau, Marty Breidenbach, Gene Fisk, Ray Frey, Tom Markiewicz, Keith Riles.

1. What are the physics reasons for wanting exceptional jet energy (mass) resolution? How do signal/backgrounds and sensitivities vary as a function of resolution? Is mass discrimination of W and Z in the dijet decay mode feasible, and necessary?

2. How does energy flow calorimetry resolution depend on such variables as Moliere radius, $\Delta\theta/\Delta\phi$ segmentation, depth segmentation, inner radius, B field, number of radiation lengths in tracker, etc.?

3. What benefits arise from very high-precision tracking (*e.g.*, silicon strip tracker)? What are the limitations imposed by having relatively few samples, and by the associated radiation budget? What minimum radius tracker would be feasible?

4. Evaluate the dependence of physics performance on solenoidal field strength and radius.