Chapter 1

Introduction and Overview

The Large Electron-Positron (LEP) Collider was the highest-energy e^+e^- collider ever built. From 1989 to 2000, it collided electrons and positrons at center-of-mass energies between 89 GeV and 208 GeV. Data collected by the four LEP detectors allow us to test the Standard Model theory of particle interactions with previously unattainable precision.

In this thesis I study the production of photonic events with missing energy at LEP. My motivation for this study is twofold:

(1) to measure the pair-production of neutrinos in e^+e^- collisions

(2) to search for evidence of physics beyond the Standard Model.

The LEP detectors were effectively transparent to neutrinos since these elementary particles interact with ordinary matter only through the weak force. As a consequence, the neutrino-pair production process could only be studied using events from the reaction $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$. In this reaction the neutrinos are produced via an exchange of the heavy W and Z bosons (the carriers of the weak force), while the photons are radiated predominantly by the incoming electrons and positrons. The corresponding photonic events necessarily appear to be unbalanced since a sizable fraction of energy is carried away by the undetected neutrinos. I select such events to measure the differential $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$ cross sections, which in turn allows me to perform a precise measurement of the number of light neutrino species and to study the triple and quartic couplings between the photon and the heavy gauge bosons.

My analysis was based on 619 pb^{-1} of data collected by the L3 detector between 1998 and 2000 at center-of-mass energies $\sqrt{s} = 189 - 208$ GeV, which corresponded to the highest energy and luminosity LEP runs. Approximately 2,000 photonic events with missing energy found in these data were used in my measurements. It should be noted that the BGO electromagnetic calorimeter of L3 stood prominently as the most accurate photon detector at LEP. Calibrated with a Radiofrequency Quadrupole (RFQ) accelerator, it provided an energy resolution of approximately 1% for photons and electrons with energies above 10 GeV. This made the L3 experiment the ideal place at LEP to study photonic event signatures.[1]

In the second part of my analysis, I use the selected sample of photonic events to search for manifestations of physics beyond the Standard Model. The Standard Model has been extremely successful in describing virtually all phenomena observed in high-energy particle collisions. Nevertheless, it also contains a number of conceptual problems which can be solved only by introducing some *new physics*.

Two of the most promising extensions of the Standard Model, Supersymmetry and models with large extra dimensions, are considered in this thesis. In e^+e^- collisions, these new particle interactions could manifest themselves through an enhanced production of single- or multi-photon events with missing energy in the reactions $e^+e^- \rightarrow X\gamma$ and $e^+e^- \rightarrow X\gamma\gamma$, respectively. Here, X represents one or more new neutral invisible particles. Different analysis techniques are used depending on the specific reaction in question. In particular, I use the high performance triggers and veto detectors of L3 to select single-photon events with energies as low as 1 GeV, which significantly increases the sensitivity of my searches for signs of extra dimensions.[2]

I have organized this thesis in three parts. In the first part (Chapters 2-3 and Appendix A), I give an overview of the theoretical context of my work. In the second part (Chapters 4-5 and Appendices B and C), I describe the experimental apparatus that I use in my study. Finally, the last part (Chapters 6-8 and Appendices D and E) covers my selection of the photonic events with missing energy as well as the measurements and searches that I perform using this event sample.

[1] The BGO resolution was at least three times as good as the resolutions of the other electromagnetic calorimeters at LEP.

[2] The other LEP experiments have not been able to develop an effective selection for photons with energies below 6 GeV.

Following is a brief outline of each chapter.

Chapter 2 begins with an overview of the Standard Model and its status with an emphasis on the electroweak interactions that are relevant to this thesis. The rest of this chapter and Appendix A are devoted to the theoretical description of the reaction $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$. In Chapter 3, I briefly describe Supersymmetry and models with large extra dimensions, concentrating on the mechanisms which could lead to an anomalous production of photonic events with missing energy.

Chapter 4 covers the LEP accelerator and the L3 detector in general. In Chapter 5 and Appendices B and C, I describe the calibration and monitoring of the BGO electromagnetic calorimeter. In particular, the RFQ calibration technique is discussed in detail. From 1997 through 2000, I coordinated the RFQ calibration runs, analyzed the RFQ data, and produced the BGO calibration constants that were used in the L3 data reconstruction. I was able to improve the RFQ calibration algorithm, which resulted in a BGO energy resolution of about 1%, the best resolution obtained since the BGO barrel was calibrated in the test beams in 1987-88.[3] The significant increase in the calibration quality and elimination of the resolution tails was crucial for my analysis of single- and multi-photon production at LEP.

In Chapter 6 I discuss the methods that I have used to select my samples of photonic events with missing energy. As part of this work, I have performed original studies of detector hermeticity, trigger efficiency, photon conversion, and cosmic contamination. These studies significantly improved the quality of my selection and reduced the systematic errors. Selection results are further detailed in Appendix D. In Chapter 7 I describe my measurements of the $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$ cross sections and my work on searches for manifestations of physics beyond the Standard Model. Combinations of my results with those of the other LEP experiments are described in Appendix E. Finally, Chapter 8 summarizes the main results of this thesis and compares them with results from other high-energy physics experiments.

[3]For comparison, calibrations used from 1989 to 1996 provided a resolution of about 2% with significant resolution tails.