Measurement of Z boson pair production and a search for the Higgs boson in e+e- collisions at LEP
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Citation for published version (APA):
van Vulpen, I. B. (2002). Measurement of Z boson pair production and a search for the Higgs boson in e+e- collisions at LEP
Chapter 1

Introduction

Throughout history it has been a great adventure for mankind to unravel the many mysteries of nature. By closely observing nature we try to find patterns or 'laws' that nature obeys. The models that have been constructed to represent nature often possess rather simple underlying principles or symmetries that can nevertheless describe its very complex behaviour. Nature is studied at many different scales and levels of complexity and in this thesis we focus on the part that studies the behaviour of the fundamental building blocks of matter and their interaction: particle physics.

In the twentieth century, physicists have gathered an enormous amount of knowledge about the world of elementary particles by performing a wide variety of experiments. At this moment all observed particles and their interactions can be accommodated in a single model called 'the Standard Model'. This model has been extremely successful in describing the results of all experiments (in some cases to below a per mill precision) over a wide range of energies. The success of this model reveals a beautiful symmetry and ordering at the most fundamental level of nature. However, in spite of its enormous success, there is a single essential piece of this model still missing: a particle called 'the Higgs boson'. This particle is a necessary ingredient of the theory for various reasons. The first reason is that it explains how particles acquire a mass. Most important in that respect is that it explains why the particles that mediate the weak force (one of the four fundamental forces in nature) are massive which in turn explains why this force only operates over small distances. In addition it also gives rise to the masses of the fundamental building blocks of matter, the quarks and leptons. The second reason that the Higgs boson is an essential part of the model is that without it the Standard Model is not renormalisable. This means that without this particle, the computations performed using this model yield meaningless results and the model has no predictive power. Including the Higgs boson in the theory solves these problems. Although there are many indications that this particle indeed exists, it has not been observed directly until this day, despite numerous searches and experiments. This thesis describes a search for the Higgs boson leading to one of the most competitive lower limits on its mass established to date.

We look for the Higgs boson in $e^+e^-$ collisions where it is produced together with another fundamental particle: the Z boson. The high energies needed to create these two particles simultaneously can only be reached in large accelerators. In this thesis we study the collisions from electrons and positrons at the Large Electron Positron collider (LEP) of the European Laboratory of Nuclear Research (CERN) near Geneva.

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The outline of this thesis is as follows. In Chapter 2 an introduction is given to the Standard Model of electroweak interactions and the characteristics of the Higgs boson are presented as a function of its unknown mass. Chapter 3 describes briefly both the LEP accelerator, where bunches of electrons and positrons are accelerated and collided and the DELPHI detector that records the particles that are produced in these collisions. We will focus on the class of events with a multi-jet (4-quark) final state. The selection of these events from all $e^+e^-$ interactions together with the tools that are used to analyse these events are explained in chapter 4. In chapter 5 these tools are used to extract information about each of the observed events at different levels of complexity. This chapter also presents the method that is used to combine this experimental information with what is expected for various processes. Also the characteristics of (and the main differences between) the various event types that produce a 4-quark final state are discussed here. This information is then used to construct a compatibility measure for the observed event to originate from each of these different processes. In chapters 6, 7 and 8 this analysis method is then applied to three different measurements. Chapter 6 describes the measurement of Z boson pair production where both Z bosons decay into a quark anti-quark pair. This process is very similar to that of Higgs boson production and serves as a 'calibration' of the method. In chapter 7 the data collected by the DELPHI detector at the highest centre-of-mass energies are used to look for the possible presence of a Higgs boson. Finally, in chapter 8, a more model independent analysis is presented by placing an upper limit on the cross section of a hadronically decaying scalar particle that is pair produced together with a Z boson.