Measurement of the W boson mass and width with the L3 detector

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Introduction

According to the ancient Greek philosophers the universe was composed of four elements or roots: Earth, air, fire and water. All matter was believed to be ultimately composed of these four elements of nature.

In about 2000 years, this view has drastically changed. The quest to the ultimate reality of which this universe is composed of has led to new insights. The study of the fundamental structure of matter and its interactions has cumulated in a theory which is at present called the “Standard Model”.

This Standard Model has been extensively verified at accelerators, where high energetic particles are brought into collision to probe the internal structure of matter.

In this Standard Model, matter exists of six leptons and six quarks. In addition: each particle has a corresponding anti-particle.

The interactions between these fundamental constituents of the matter particles are described by the exchange of other particles, called bosons. Four types of interactions, also called forces, exist. The strong force is felt by the quarks and is carried by the gluons. Charged particles interact via photons, which are the carriers of the electromagnetic force. The weak force, which is for example responsible for the decay of neutrons, is carried by three heavy bosons $W^+$, $W^-$ and $Z$. Gravitation, which is believed to be carried by the graviton, is the weakest of the four forces. From the bosons which carry the forces only the graviton is not yet observed. Except for gravitation the Standard Model has been successful in describing the other three forces in its framework.

The $W^+$ and $W^-$, which are denoted in shorthand notation as $W$, are the subject of study in this thesis. One of the important properties of the $W$-boson is the mass, which we want to determine.

At the end of the 1960s the theory predicted the existence of the $W$ boson. However, it took until 1983 to produce them in an experiment and observe them directly at the proton-antiproton collider (SPS) at the European Laboratory for particle physics (CERN). This was one of the big triumphs of particle physics.

In 1989 the Large Electron Positron (LEP) accelerator and its four detectors ALEPH, DELPHI, L3 and OPAL became operational. In the first phase of LEP the machine operated at around a centre-of-mass energy ($\sqrt{s}$) of 91 GeV. Since this energy is close to the mass of the $Z$ boson, $Z$'s were produced on resonance.

In 1996 the second phase of LEP started. The centre-of-mass energy was increased to 161 GeV, which is approximately twice the mass of the $W$ boson. This allowed the production of $W$ pairs as $\sqrt{s}$ was higher than the threshold energy of twice the mass of the $W$ boson. Gradually the energy was increased to around 208 GeV.
In this thesis the data taken with the L3 detector is analysed to measure the mass of the W boson. The relevant theoretical aspects are described in chapter 1. The description of particles in the Standard Model framework and how these particles acquire mass is summarised in the first part of this chapter. In the second part of chapter 1 the theoretical facets of the experimental aspects of the production and decay of W bosons are outlined. In chapter 2 LEP and the L3 detector are described. This is followed by the selection of the relevant events for the analysis in chapter 3. Chapter 4 puts the focus on the kinematic fit, which aims to improve the measurement of the observed variables. The W mass analysis results are presented in chapter 5 and the systematic uncertainties in chapter 6. The last chapter is devoted to the comparison with other experiments and an outlook on future experiments is given.