Direct measurement of the W boson mass in $e^+ e^-$ collisions at LEP
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In some fundamental respects W bosons are identical to photons (light particles). One major difference, however, is that W bosons are quite heavy while photons are massless. The measurement of the mass of the W boson is the subject of this thesis. With a mass of about $1.43 \cdot 10^{-25}$ kg they are almost 86 times as heavy as a proton. This large W mass is part of the reason that W bosons are not so ‘visible’ in daily life, compared to photons. The other reason is that their lifetime is short: $3.2 \cdot 10^{-25}$ seconds. Nevertheless their existence plays an important role in our current understanding of the universe. W bosons are the carriers of the Weak nuclear force.

Because of the large mass of the W boson, high energies are needed to produce them in a particle collider. After the prediction of the existence of the W boson and its neutral partner, the Z boson, at the end of the 1960s, it was not until 1983 that the W and Z bosons were actually produced for the first time at the proton-antiproton collider (SFS) at the European Laboratory for particle physics (CERN) in Geneva. In 1989 the largest scientific instrument ever built, the Large Electron Positron collider (LEP) at CERN, was switched on. During the first years (LEP1 phase) it was used to produce millions of Z bosons and study their properties. Subsequently the energy was increased and in 1996 the WW production threshold was passed, so that the properties of W bosons could be studied as well.

The subject of this thesis is the measurement of the mass of the W boson directly from the invariant mass of its decay products, using the DELPHI detector at LEP. The combination with the results of the other 3 collaborations at LEP will yield a direct measurement of the W mass more precise than ever before, thus allowing important tests of the Standard Model and also enabling an improved prediction of the mass of the elusive Higgs particle, the only particle in the Standard Model that has not yet been observed.

The theoretical motivation of the measurement will be elucidated in a slightly more quantitative manner in chapter 1, while chapters 2 and 3 deal with the more experimental aspects of the production, decay and observation of W bosons at LEP. Chapter 2 focuses on the relevant physics processes and phenomenological models used to describe them. This includes final state gluon radiation, jet fragmentation and possible final state cross-talk between the W bosons in hadronic final states. Furthermore the ‘line-shape’ of the W boson is defined here, used to define the W mass and the width observables. The aim of this chapter and of chapter 3, describing LEP and the DELPHI detector, is to highlight the main physics processes and experimental properties that are vital to understand and control the measurement.

The following chapters are dedicated to a detailed description of the analysis techniques used. The methods developed for this thesis have been (and still are) the baseline analysis for the DELPHI results in the fully hadronic channel. This thesis therefore details the evolution and final
version of this analysis which includes several novel techniques in an ‘Ideogram’ framework. First in Chapter 4 a few basic analysis tools are reviewed, namely jet clustering, constrained fit, Monte Carlo reweighting and the Jackknife method. Chapter 5 describes how these basic analysis tools were combined to construct the Ideogram analysis. It will give an overview of the development of the analysis by briefly outlining the different versions employed by DELPHI to analyse the data sets at 172, 183 and 189 GeV. The final analysis, identical to the 189 GeV version, is presented in a comprehensive manner in Chapter 6. In addition to the measurement of the W mass and width, a method to measure the difference $m_{W^+} - m_{W^-}$ is also proposed. Furthermore a feasibility study of a similar approach in the semileptonic channel is presented but with less detail.

A crucial part of the W mass analysis is the treatment of systematic errors. A careful study is presented in chapter 7, including the main conclusions obtained from a new and highly sensitive technique based on Mixed Lorentz Boosted Z boson events (MLBZ).

The final results on W mass, width and the difference between the masses of the $W^+$ and the $W^-$ bosons are presented in chapter 8, and a conclusion and outlook are given. Appendix A contains a detailed discussion of the MLBZ method and its results.

The work presented in this thesis has taken place from 1996 to 2001. Some of the results have already been published [1, 2, 3, 4, 5], while the analysis method has been described in some detail in [6].