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

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Summary

The Standard Model theory in the weak interaction sector predicts the existence of the spin-1 bosons: the photon $\gamma$, the neutral Z boson and the charged W boson. Both the Z and W bosons were discovered in 1983 in $p\bar{p}$ collisions at CERN. The W boson is a massive particle. However, the mass is not predicted by the theory. It has to be determined experimentally. The mass and decay width of the charged W boson is the subject of study in this thesis.

One of the main physics goals of the Large Electron Positron (LEP) collider was the measurement of the mass and width of the W boson. In the first phase of LEP the centre-of-mass energy was approximately equal to the mass of the Z boson. In this phase the properties of the Z boson were extensively studied. In the second phase of LEP the centre-of-mass energy was increased to the W pair production threshold energy and above. These energies made it possible to directly measure the properties of the W particle.

This thesis describes the measurement of the W boson mass and width at the LEP collider with the L3 detector. The analysis presented in this thesis is based on the recorded data from 1998 until 2000. During this period the centre-of-mass energy was increased from 189 to 208 GeV. The total luminosity collected for these years is 629.3 pb$^{-1}$.

Due to the fact that the W is an unstable particle with a very short lifetime, only the decay products are observed in the detector. The W can decay to a lepton-antineutrino or to a quark-antiquark pair. The four decay channels analysed in this thesis are: $qq\nu$, $q\bar{q}\nu$, $q\bar{q}\tau$, and $qqq$ channel. The first three channels are the semi-leptonic channels, while the fourth is called the fully hadronic channel. These events are selected out of other processes which looks very similar to the desired events. They are separately selected, according to their specific properties and analysed.

From the invariant mass distribution of these selected events the mass of the W is determined. The invariant mass is calculated from the energy and angular information of the event. Parameters are measured with a finite precision in the detector. Resolution effects smear the measurements and worsen the reconstruction and therefor the measurement of the mass. A kinematic fit procedure is used in chapter 4 to resolve this problem.

The mass is determined by fitting the invariant mass distribution of the reconstructed selected events with a maximum likelihood method. The cross-section and the differential cross-section, on which the likelihood function depends, are calculated with a so-called boxmethod. One Monte Carlo sample with a certain generated mass and width is reweighted by calculating weight factors for each event in the Monte Carlo to simulate a Monte Carlo with a different mass or width.

Systematic uncertainties arise from the measurement process and the physics behind. Possible sources of systematics effects are studied, including Monte Carlo statistic, background, lepton and jet measurement, initial and final state radiation, fragmentation, colour reconnection, Bose-
Einstein correlation and uncertainties in the LEP beam energy measurement. These effects and results are thoroughly discussed in chapter 6.

Combining all the measurements of the semi-leptonic and fully hadronic decay channels and systematic effects for the data analysed in this thesis yields:

\[ M_W = 80.323 \pm 0.047\,\text{(stat)} \pm 0.051\,\text{(syst)} \, \text{GeV}, \]
\[ \Gamma_W = 2.27 \pm 0.12\,\text{(stat)} \pm 0.07\,\text{(syst)} \, \text{GeV}, \]

where the first uncertainty is statistical and the second uncertainty arises from systematic effects. The main contribution in the systematics comes from colour reconnection, a process that can occur between quarks in the final state, and the fragmentation modelling that describes the evolution of a produced quark to the observed jet.

The next generation of colliders will probe deeper into the structure of matter and will comprise two complementary types of colliders: the Large Hadron Collider (LHC) and a high-energy high-luminosity electron-positron linear collider type. These future colliders will significantly improve the measurement of the W boson mass.