Measurement of Z boson pair production and a search for the Higgs boson in e+e-collisions at LEP
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Summary

In this thesis an analysis is presented that studies high energy $e^+e^-$ collisions in which four (or more) jets of particles are created. These collisions are produced by the Large Electron Positron collider (LEP) at CERN with centre-of-mass energies ranging from 183 to 209 GeV and correspond to a total integrated luminosity of 665 pb$^{-1}$. The particles that are produced in these collisions are recorded by the DELPHI detector.

The main goal of this thesis is to search for the possible presence of interactions (events) that can be attributed to the last missing particle of the Standard Model, the Higgs boson. This particle is a crucial ingredient in the model that describes the world of elementary particles as it not only explains how particles acquire mass, but in addition ensures that the model can provide precise predictions for their interactions. Although the mass of the Higgs boson itself is not predicted, all its further properties are. At LEP, if kinematically allowed, the Higgs boson is mainly produced together with a Z boson and in this thesis we are interested in the events in which both the Z boson and the Higgs boson decay into a quark anti-quark pair, which results in four quarks in the final state: $e^+e^-\rightarrow ZH \rightarrow q\bar{q}q\bar{q}$. These fully hadronic Higgs events ($\sim 2/3$ of all possible final states) have very distinct properties. Unfortunately, even if the Higgs is produced, only a small number of ZH events are expected, with the additional complication that the heavier the Higgs boson is, the less events are produced. The main challenge is therefore to isolate possible candidates from the large sample of 'background' multi-jet events.

An analysis is presented that is sensitive to both Higgs events and other Standard Model processes that produce four quarks in the final state. This is achieved by comparing, on an event-by-event basis, the experimental information extracted from the event with what is expected from each of these different event types. In this comparison the predicted properties are used analytically where possible which allows to optimally take into account the characteristics of the Higgs boson as a function of its (unknown) mass. For each event a compatibility measure with all hypotheses is computed. The analysis presented in this thesis differs from other Higgs analyses mainly in the way the mass information is treated and in the method that is used to combine event information from various levels of complexity. The main advantage of this method is that the inherent ambiguity in multi-jet events connected to the pairing of jets does not need to be resolved. This allows the construction of a more complete and consistent compatibility measure with Higgs events (and other hypotheses).

The process of Z boson pair production where both Z bosons decay into a quark anti-quark pair ($e^+e^-\rightarrow ZZ \rightarrow q\bar{q}q\bar{q}$) is very similar both in experimental signature and cross section to that of Higgs events. Although an interesting process in itself, it is a background in the search for the
Higgs boson and therefore an ideal process to 'calibrate' the analysis method. The cross section for this process has been measured at all LEP2 centre-of-mass energies and is found to be in good agreement with the Standard Model expectation. The related measurement of the (small) fully hadronic ZZ cross section in which there are at least two b-quarks present (~ 0.2 pb) is summarised by the good agreement between measurement and expectation when the combined LEP2 data set is used:

$$\frac{\sigma_{\text{measured}}}{\sigma_{\text{SM}}}(b\bar{b}q\bar{q}) = 1.05^{+0.17}_{-0.15(\text{stat})}$$

This result shows that the analysis is indeed sensitive to a signal that is very similar to ZH events. However, in the data set that was analysed, no evidence for the presence of the Standard Model Higgs boson was found. Since the cross section of ZH production gets smaller as the Higgs mass increases, at very large Higgs masses the analysis is no longer sensitive to a possible Higgs signal and the analysis can no longer exclude the presence of such a (small) signal. The search for the Higgs boson is summarised by the largest mass of the Higgs boson that can still be excluded at 95% confidence level. The expected and observed lower limit on the mass of the Standard Model Higgs boson in the 4-quark channel are:

- Expected: $M_H > 112.0$ GeV/c$^2$ (at 95% CL)
- Observed: $M_H > 112.2$ GeV/c$^2$ (at 95% CL)

The clearest signature of a ZH event is the presence of a pair of b-quarks in the final state as this is the dominant decay mode of a Standard Model Higgs boson and jets of particles originating from the fragmentation of a b-quark can be clearly identified experimentally. There are, however, also models in which the Higgs boson coupling to b-quarks is significantly lower than in the Standard Model and the Higgs might decay exclusively to a pair of light quarks or gluons. To be able to confront specific models with the data from $e^+e^-$ collisions, an upper limit on the cross section is derived for a scalar object that decays hadronically and that is produced together with a Z boson. These cross section limits are presented as a function of the mass of this scalar particle and present a more complete and model independent analysis of the collected multi-jet event sample. If the cross section is assumed to be identical to that in the Standard Model, the measurement can also be translated into a lower limit on the mass of such a scalar particle. Using the analysis presented in this thesis an expected(observed) lower limit of 103.9(106.9) GeV/c$^2$ is obtained at 95% CL.

As the LEP experiments can not claim to have observed the Higgs boson, the search for this elusive particle continues. With the new proton (anti-)proton colliders at Fermilab and CERN it is very likely that, if the Higgs boson exists, it will be discovered in the coming five to eight years.