STANDARD MODEL HIGGS SEARCH AT LEP IN CHANNELS OTHER THAN FOUR JETS

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The LEP centre of mass energy has been increased since 1996 in the aim of producing the Higgs boson. The SM Higgs boson search has been pursued in the four LEP collaborations exploiting final states with higher branching ratios. In the following we discuss the search in final states with two jets and missing energy or charged leptons.

1 Introduction

In the year 2000 the four LEP experiments collected data at centre of mass energies between 200 and 209 GeV, integrating approximately 870 pb\(^{-1}\) of luminosity. The results presented here are based on the analysis published soon after the end of data taking.

At LEP the Higgs is expected to be produced mainly via Higgstrahlung process \(e^+e^- \rightarrow HZ^0\) and via the WW-fusion: \(e^+e^- \rightarrow WW\nu\nu \rightarrow H\nu\nu\) which has nearly the same contribution at kinematic limit \(m(H) = \sqrt{s} - m(Z^0)\). The contribution from the ZZ-fusion process is an order of magnitude smaller than the WW-fusion process.

For the masses accessible at LEP the Higgs decays mainly into b quarks. For an Higgs mass of 115 GeV/c\(^2\) the BR(\(H \rightarrow b\bar{b}\)) is 78\% and the BR(\(H \rightarrow \tau^+\tau^-\)) is 7.5\%. Thus the Higgs search is divided into channels with final states characterised by the decays of the \(Z^0\): 4-jets (\(HZ^0 \rightarrow b\bar{b}q\bar{q}\)) for 56\% of the cases; 2-jets and missing energy (\(HZ^0 \rightarrow b\bar{b}\nu\nu\)) for 16\%; leptonic (\(HZ^0 \rightarrow b\bar{b}\ell^-\ell^+\) and \(HZ^0 \rightarrow b\bar{b}\mu^+\mu^-\)) for 5\% and taus (\(HZ^0 \rightarrow b\bar{\tau}^{-}\tau^+\) and \(\tau^-\tau^+b\bar{\tau}\)) for 8\% of the cases.

Due to the different background composition and mass resolution, the missing energy final state together with the leptonic and taus final states have the same search potential as the four jets final state (see figure [1]) despite the branching ratio being nearly one half.
2 The search strategy

The cross section for Higgs of 115 GeV/c² is 0.058 picobarn at 207 GeV centre of mass energy, while the background processes have cross sections of the order of several tens of picobarn ($e^-e^+ \rightarrow q\bar{q}\gamma$, $e^-e^+ \rightarrow WW$) or even several hundreds of picobarn ($e^-e^+ \rightarrow e^-e^+X$). The strategy followed by the LEP collaborations to select the signal is based on two step analysis: firstly a series of sequential cuts is applied to reject the bulk of background, secondly a likelihood or a Neural Network is used to profit from the different kinematic distributions of signal and background.

2.1 The sequential cuts

In the process $e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-X$, electron and positron of the final state escape detection since they go down the beam pipe. As a consequence the total visible energy in the plane perpendicular to the beam line is low and the spectrum of visible invariant mass is concentrated at low values. In all Higgs search it is possible to reduce the two photons background by cutting on the two previous variables.

Another cut common to all the analysis is based on the polar angle of missing momentum and the effective centre of mass energy after initial radiation. In the $e^+e^- \rightarrow q\bar{q}$ process the effective centre of mass energy can be considerably reduced by the photon emission, and since the radiation is more likely along the beam pipe the missing momentum points at low polar angle.

2.2 The likelihood and the Neural Network

Several variables have different shape in the distribution in the phase space for signal and background. The informations given by several kinematic distributions is combined using a likelihood technique or a Neural Network and the output is a discriminant variable that allows to reach a high Higgs signal efficiency and high background rejection. The two dimensional distribution of the discriminant variable and the mass of the candidates is used to give the
signal over background ratio for each event. A test statistic is then constructed:

\[
\ln(Q) = -s_{TOT} + \sum_{i=1}^{N} n_i \ln(1 + \frac{s_i}{b_i})
\]

where \(N\) is the total number of selected events, \(s_{TOT}\) is the total signal rate and \(s_i/b_i\) is the signal over background ratio for the event \(i\). The observed value of \(\ln(Q)\) is compared with the expected value from signal and background experiments and the confidence levels of signal CL\(_s\) and of background CL\(_b\) are derived.

3 \(H\nu\tau\) final state

This is the second most likely final state. The energy flow and the jet reconstruction are two fundamental items to correctly reconstruct the Higgs mass. To improve the resolution it is possible to impose the recoil mass to be the \(Z^0\) mass. The drawbacks of this method are:

- in the events \(e^+e^- \rightarrow WW\nu_e\nu_e \rightarrow H\nu_e\nu_e\) the recoil mass is wrongly reconstructed;
- in the events at rest the mass is artificially reconstructed at the kinematic limit \(\sqrt{s}-m(Z)\) where the signal is expected, decreasing the signal over background ratio.

The most difficult task is the treatment of the \(q\bar{q}\gamma\gamma\) background. In case each of the two photons is emitted symmetrically by the electron and positron and they are lost in the beam pipe, the event is signal like: two visible jets in the final state with high invariant mass and high missing energy. The only possibility to discriminate this background from the signal is to consider the acoplanarity of the two jets: in the case of symmetric double radiative events, the two jets are nearly coplanar, while in the signal case the events may be acoplanar even at the kinematic limit due to the \(Z^0\) width and to the WW fusion contribution to the Higgs production.

Among the LEP candidates with higher signal over background ratio (see table 1) there are 3 \(H\nu\tau\) events. The first has the two jets mass equal to 114.4 GeV/c\(^2\), and a missing mass of 94 GeV/c\(^2\). It has a high value of b-tag and the acollinearity is 3 degrees.

| \((s/b)_{115}\) | \(M_{rec}\) | Channel | Exp. |
|-----------------|------------|---------|------|
| 4.7             | 114        | Hqq     | ALEPH|
| 2.3             | 112        | Hqq     | ALEPH|
| 2.0             | 114        | H\nu\tau| L3   |
| 0.9             | 110        | Hqq     | ALEPH|
| 0.6             | 118        | H\nu^+\nu^-| ALEPH|
| 0.52            | 113        | Hqq     | OPAL |
| 0.5             | 111        | Hqq     | OPAL |
| 0.5             | 115        | H\tau^+\tau^-| ALEPH|
| 0.5             | 115        | Hqq     | ALPEH|
| 0.49            | 114        | H\nu\tau| L3   |
| 0.47            | 115        | Hqq     | L3   |
| 0.45            | 97         | Hqq     | DELPHI|
| 0.40            | 114        | Hqq     | DELPHI|
| 0.32            | 104        | H\nu\tau| OPAL |
4 Final state with charged leptons

In these channels the background contamination can be reduced to a smaller contribution than is possible for the other final states for the same signal efficiency. Using constrained fits, the mass resolution can reach values of 2-3 GeV/c^2 and the typical problems of jet pairing of the four jets final states, or of energy flow of the missing energy channel are avoided. A particular care must be dedicated to the radiated photons from the high energetic leptons in final state. If these photons are wrongly associated to the jets, they can artificially increase the two jets invariant mass and simulate a signal.

An $He^+e^-$ and an $H\tau^+\tau^-$ are among the first 8 LEP candidates with highest signal over background ratio (see table 1).

![Figure 2: $1-C_{Lb}$ for missing energy and charged leptons final states.](image)

5 Conclusions

The confidence level of the background for the selected events in the missing energy and leptonic channels can be extracted (see figure 2). There is an overall excess of events in data with respect the expected events from Standard Model prediction, and this excess results in a discrepancy of the order of one sigma from the expected and observed confidence level of the background.

All LEP collaborations are reviewing their analysis taking into account the final calibration of detectors, and more MonteCarlo statistic: the final word from LEP on Higgs will come in the forthcoming few months.

References

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