Search for the Standard Model Higgs Boson in OPAL

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Abstract

A search for the Standard Model Higgs boson with the OPAL detector at LEP was reported. The analysis was based on the full data sample collected at $\sqrt{s} \approx 192–209$ GeV in 1999 and 2000, corresponding to an integrated luminosity of approximately 426 pb$^{-1}$. The data shows an excess in a range of 95–120 GeV. The data slightly favour the hypothesis that a signal is present, but also that the data are consistent with the background hypothesis. A lower bound of 109.7 GeV is obtained on the Higgs boson mass at the 95% confidence level.

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1 Introduction

In year 2000, a number of improvements were made to the LEP collider. It increased Higgs discovery potential up to approximately 115 GeV if LEP combination were made. In LEPC held in November 2000, an excess of candidates, which is compatible with the Standard Model(SM) Higgs boson of 115 GeV, was reported [1]. The results of a search for the SM Higgs boson with the OPAL detector at LEP was reported in this talk based on the results described in published letter [2].

2 The Analyses

The data used in the analyses correspond to integrated luminosities of approximately 216 pb$^{-1}$ at 192–202 GeV, 80 pb$^{-1}$ at 203–206 GeV, and 130 pb$^{-1}$ at centre-of-mass energies ($\sqrt{s}$) higher than 206 GeV. During 2000 (1999), data were taken at $\sqrt{s} = 200$-209 GeV (192-202 GeV) with a luminosity-weighted mean $\sqrt{s}$ of 206.1 (197.6) GeV.

The analyses follows our previous publication[3]. The search was performed in the following final states, $H Z \rightarrow b \bar{b}q \bar{q}$ (four-jet), $H Z \rightarrow b \bar{b} \tau^+ \tau^-$ and $\tau^+ \tau^- q \bar{q}$ (tau), $H Z \rightarrow b \bar{b} e^+ e^-$ and $H Z \rightarrow b \bar{b} \mu^+ \mu^-$ (electron and muon).

In all channels, preselections followed by likelihood selections were applied to select the Higgs signal. The likelihood consists of b-tagging information, event shape variables, lepton identification, (in)compatibilities to the signal(background) mass hypothesis and so on. The likelihood selection were optimised using a mixture of various masses of signal Monte Carlo samples. Hence, the selection was not optimized to a particular mass.

The b-tagging variable $B$ is a likelihood combination of three independent b-tagging information, lifetime sensitive part, jet kinematics and lepton $p_T$ information. Lifetime sensitive part is an artificial neural network consists of four input variables including both displaced vertex and track impact parameter information. The performance of b-tagging was checked using the calibration data taken at $Z^0$ peak in 2000, as well as higher energy data as shown in Figure 1.

![Figure 1](image_url)

Figure 1: The b-tagging performance and modeling for (a–b) calibration data taken at $Z^0$ pole, and (c–d) at 200–209 GeV in 2000. (a) The distribution of the b-tagging variable $B$ for jets (b) The bin-by-bin difference between data and Monte Carlo simulation for b-enriched(circles) and b-suppressed(squares) samples. (c) The b-tagging output for opposite b-tagged jets in a sample of $q \bar{q} \gamma$ events, and (d) for jets in a sample of $W^+W^- \rightarrow \ell \nu q \bar{q}$ ($\ell = e$ or $\nu$) events.
Figure 2: Left: The likelihood distributions for each channels OPAL data are shown with points, backgrounds with the shaded histograms, and the expectation from a signal with $m_{H^0} = 115$ GeV with the dashed histograms (scaled up by a factor of 100 for visibility. Right: The reconstructed mass distribution for the selected events.

The number of selected events in all search channels was 156 with $146.1 \pm 11.9$ expected from the SM background processes. Figure 3 shows the likelihood distributions of each channels after preselection and the reconstructed mass distributions after likelihood selection.

After the event selections search channels were combined using the likelihood ratio method [4] or the method described in previous paper [3]. Three different final discriminants, “test statistic”, were used in different channels to reflect the different background conditions. The four-jet channel uses a likelihood consists of four variables including b-tagging, reconstructed mass and two event shape parameters. The missing energy, electron and muon channel uses likelihood calculated from mass and selection likelihood output. The tau channel uses simply the mass distribution as a test statistic.

3 Results

Figure 3(a) shows the log-likelihood ratio as a function of test mass. The two bands in the figure are 68% and 95% contours centred on the median expectation. Figure 3(b) shows the projection of (a) at test mass of 115 GeV, corresponding to the probability density of $-2 \ln Q$ for signal+background and background only hypotheses. The background confidence level ($1 - CL_b$) and signal+background confidence level (CL$_{s+b}$) are 0.2 and 0.4 shown in dark and light shaded area in the figure, respectively.

The Figure 3(a) shows $1 - CL_b$ as a function of the test mass. An excess can be seen in a range of 95–120 GeV with the lowest value of 0.02 at 107 GeV. The probability to observe such an excess anywhere in the range of test masses between 95 and 120 GeV is approximately 10%, estimated from the size of the range and the reconstructed mass resolution. The expected curve in the presence of 115 GeV Higgs is also seen in the figure.

The signal rate limit $n_{95}$ observed in data is shown as a function of $m_{H^0}$ in Figure 3(b) together with its median expectation in background-only hypothesis. Figure 3(b) also shows the expected accepted signal rate. A lower mass bound of 109.7 GeV was obtained, and the expected limit was 112.5 GeV.
Figure 3: (a) The log-likelihood ratio $-2 \ln Q$ as a function of the test mass $m_{H^0}$. The observation for the data is shown with a solid line. The dashed line indicates the median background expectation and the dark (light) shaded band shows the 68% (95%) probability intervals. The median expectation in the presence of a signal is shown with a dot-dashed line. (b) The expected $-2 \ln Q$ distribution for background only (solid line) and with a 115 GeV Higgs boson (dashed histogram). The observation in the data is shown with a vertical solid line.

Figure 4: (a) The background confidence level $1-\text{CL}_b$, as a function of the Higgs boson test mass. The dotted curve represents the median expectation assuming the presence of the Higgs boson with a 115 GeV mass. The dark (light) shaded bands indicate the 68% (95%) probability intervals. (b) Upper limits on the signal counts at the 95% confidence level, $n_{95\%}$, as observed (solid line) and the expected median (dot-dashed line) for expected background as a function of the Higgs boson test mass. The expected rate of the accepted signal counts for a SM Higgs boson is shown with the dotted line.
4 Summary

A search for the Standard Model Higgs boson has been performed with the OPAL detector at LEP based on the full data sample collected at $\sqrt{s} \approx 192–209$ GeV in 1999 and 2000. The largest deviation with respect to the expected SM background in the background confidence level, $1-\text{CL}_{b}$, is 0.02 at 107 GeV. The observed excess is less significant than that expected for a SM Higgs boson with a 107 GeV mass. A lower bound of 109.7 GeV on the mass of the SM Higgs boson is obtained at the 95% confidence level while the median expectation for the background-only hypothesis is 112.5 GeV. For a Higgs boson with a mass of 115 GeV, $1-\text{CL}_{b}$ is 0.2 while $\text{CL}_{s+b}$ is 0.4, indicating that the data slightly favour the hypothesis that a signal is present, but also that the data are consistent with the background hypothesis.

References

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