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SEARCH FOR THE HIGGS BOSON IN $H \to WW^* \to \ell\nu\ell\nu$ DECAYS

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We present a search for the standard model (SM) Higgs boson decaying to a pair of W bosons that in turn decay leptonically, $H \to WW^* \to \ell\nu\ell\nu$. We consider events produced in p$\bar{\text{p}}$ collisions at $\sqrt{s} = 1.96$ TeV, with two oppositely charged lepton candidates (e^+e^-, $e^\pm\mu^\mp$, or $\mu^+\mu^-$), and missing transverse energy. The data were collected with the D0 detector at the Fermilab Tevatron collider, and correspond to an integrated luminosity of 5.4 fb^{-1}. No excess of events over background is observed, and limits on SM Higgs boson production are determined.

1 Introduction

The standard model (SM) of particle physics provides predictions covering a wide range of physics phenomena. It has been tested extensively during the last four decades, and verified with great accuracy. Despite its success, the SM cannot explain the fact that elementary particles have masses. The Higgs mechanism[1,2,3] provides an explanation for the masses of the weak bosons and (indirectly) of the leptons. This mechanism hypothesizes the existence of a scalar particle, the Higgs boson, that has not been observed and whose mass is not predicted by the theory.

Particle physics experimentalists have searched for the Higgs boson for more than two decades, using different strategies for a light Higgs boson and for a heavy one. Searches for a light Higgs boson (with mass $m_H \lesssim 135$ GeV) have been performed in the past[4], without any success. Searches for a heavy Higgs boson (with mass $m_H \gtrsim 135$ GeV) became possible only recently with the dataset being collected at the Tevatron collider. In this study we present a search for a heavy Higgs boson, which is expected to decay predominantly to a pair of W bosons ($H \to WW^*$). While most W bosons decay into hadrons, almost one third of them decay leptonically ($W \to \ell\nu$). We look for events where a Higgs boson is produced and decays through the decay chain $H \to WW^* \to \ell\nu\ell\nu$. These events can be selected with the signature of two oppositely charged leptons and missing transverse energy (the latter due to the neutrinos escaping the detector without interacting). Using this kind of identification, we can look for rare processes, such as the production of a Higgs boson, that is expected to have $\sigma(\text{p}\bar{\text{p}} \to H) < 1$ pb at $\sqrt{s} = 1.96$ TeV.

In this search, we select events by applying few simple kinematic requirements (as described in Sec.2). Using a multivariate technique (described in Sec.3), we then separate the large background contribution from a potential Higgs boson signal. In Sec.4, we compute limits on the cross section for SM Higgs boson production in the mass range $115 < m_H < 200$ GeV.

2 Samples and Event Selection

Candidate Higgs boson events are selected from a sample of data collected with single and dilepton triggers. The data sample used in this study was recorded at the D0 experiment[5] between April 2002 and June 2009, and corresponds to an integrated luminosity of 5.4 fb^{-1}. Observed data distributions are compared with the expected background-only and signal+background hypotheses. Signal predictions are computed taking into account three production mechanisms: gluon-gluon fusion ($gg \to H$), associated production (WH/ZH), and vector boson fusion ($gg \to q\bar{q}H$). Background predictions are estimated taking into account the following processes: diboson production, W(+jets), Z/γ^*(+jets), $t\bar{t}$, and multijet where jets are misreconstructed as leptons. Predictions for the signals yields are computed with PYTHIA[6] simulations, and normalized to NNLO calculations. Background predictions for W(+jets) and Z/γ^*(+jets) are simulated with ALPGEN[7] and normalized to NNLO predictions[8]. The other backgrounds are simulated with PYTHIA; the $t\bar{t}$ background is normalized to NNLO calculations[9] and the diboson backgrounds are normalized to NLO calculations[10]. The multijet background is estimated from data, using an orthogonal, same-charge dilepton sample.

The event selection is performed in two steps, described in the following two paragraphs. In the first selection step ("preselection"), we require that events have the most important features expected for a Higgs boson candidate. In the second selection step ("final selection"), we reject events that are likely to come from background processes.

Events considered in this study have two leptons reconstructed; the two leptons can be two electrons (e^+e^-), an electron and a muon ($e^\pm\mu^\mp$), or two muons ($\mu^+\mu^-$). They are required to originate from the same primary vertex, and to have high transverse momentum (p_T). The transverse momentum selection criteria is based on the lepton type: electrons must have $p_T^e >$ 15 GeV, while for muons $p_T^\mu > 10$ GeV (but in a dimuon event, the muon with highest p_T must have $p_T^\mu > 20$ GeV). Further details on the algorithms used for electron and muon reconstruction can be found in the full paper[11] and the references therein.

The criteria used to reject background events are based on the kinematic variables of the event. Many of the following criteria are aimed at suppressing the most significant background process, namely Z/γ^*(+jets). We require the azimuthal opening angle between the two leptons, $\Delta\phi(\ell\ell)$, to be either $\Delta\phi(\ell\ell) < 2.0$ rad (for e^+e^- and $e^\pm\mu^\mp$) or $\Delta\phi(\mu\mu) < 2.5$ rad (for $\mu^+\mu^-$). The missing transverse energy $\not\!\!E_\text{T}$, is required to be $\not\!\!E_\text{T} > 20$ GeV (for e^+e^- and $e^\pm\mu^\mp$), or $\not\!\!E_\text{T} > 25$ GeV (for $\mu^+\mu^-$). In e^+e^- and $e^\pm\mu^\mp$ events, the scaled missing transverse energy[12], ${\not\!\!E_\text{T}}^{Sc}$, is required to be ${\not\!\!E_\text{T}}^{Sc} > 6$. The minimum transverse mass, $M^T_{min}\ (l, \not\!\!E_\text{T})$, defined as the smaller of $M_T(\not\!\!E_\text{T}, \ell_1)$ and $M_T(\not\!\!E_\text{T}, \ell_2)$, is required to be $M^T_{min}\ (l, \not\!\!E_\text{T}) > 20$ GeV ($> 30 GeV$ for e^+e^-).

After applying the selections described above, we train a multivariate discriminant to improve the separation between signal and background.

3 Multivariate Discriminant

Multivariate techniques provide an improved signal-background discrimination compared to simple cut-based analysis; this is accomplished by exploiting the correlations between the quantities characterizing the reconstructed events.

In this study, we use an Artificial Neural Network (NN) discriminant, as implemented in the `TMultiLayerPerceptron` class within the `ROOT` package[13]. We use twelve variables as inputs to the NN, after checking that all are properly modeled by the MC simulation so as not to induce a bias in the NN output distribution. The input variables, described in detail in the full paper[11], are transverse momenta (of each lepton and of the dilepton system), the invariant mass $M_{\ell\ell}$, the missing transverse energy $\not\!\!E_\text{T}$, the minimum transverse mass $M^T_{min}\ (l, \not\!\!E_\text{T})$, lepton quality variables, and opening angles between leptons or between the $\not\!\!E_T$ and leptons.

We consider Higgs masses m_H in the range $115-200$ GeV. Because the characteristics (and the yield) of signal events depend on the value of m_H, we optimize the final discriminant for each of the mass points that we consider, namely in 5 GeV steps. In Fig. 1(a) we show the distribution (at final selection) of the NN output trained for $m_H = 165$ GeV, the mass region where this analysis has the greatest expected sensitivity. For all the mass values, the distribution of the NN output for data after subtracting the expected background does not display any excess in the signal region. Fig.1(b) shows the distribution of the output for a NN trained for a signal with $m_H = 165$ GeV, after subtracting the expected background. The systematic uncertainty, represented by an error band corresponding to ±1 standard deviation, is obtained after fitting the data to the background-only template[14].

For all m_H values considered, we do not observe any excess of data that could correspond to Higgs boson events. We therefore proceed to compute upper limits on the SM cross section for Higgs boson production.

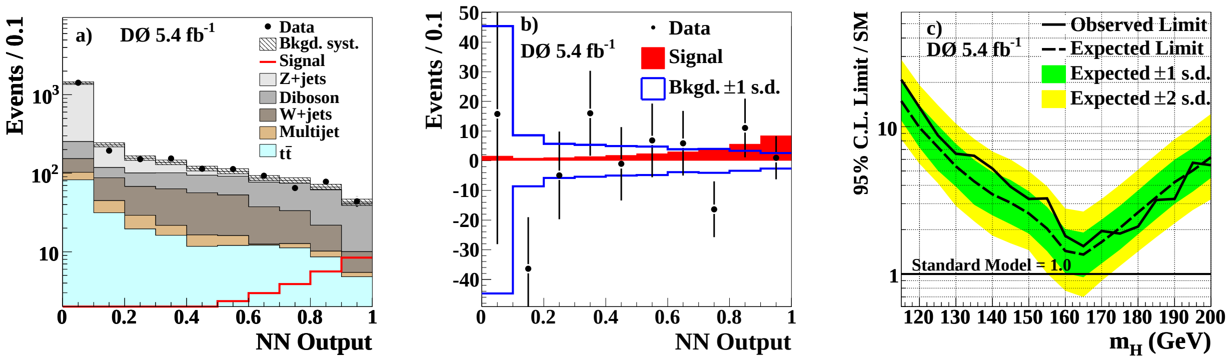

Figure 1: (color online) (a) The neural network output after final selection, with a signal corresponding to m_H=165 GeV. (b) Data after subtracting the fitted background (points) and SM signal expectation (filled histogram) as a function of the NN output for m_H=165 GeV. Also shown is the ±1 standard deviation (s.d.) band on the total background after fitting. (c) Upper limit on Higgs boson production cross section at 95% C.L. expressed as a ratio to the SM cross section.

4 Limits

Limits on the SM cross section for Higgs production are computed considering the NN distributions, and using a modified frequentist approach as implemented in the COLLIE[15] package.

Systematic uncertainties are taken into account when calculating the limits. Two types of systematic uncertainties are considered: uncertainties that affect only the number of expected events (normalizations), and uncertainties that also affect the shape of the NN output distribution (shapes). Normalization uncertainties include: theoretical cross sections (for signal and background samples), multijet estimation, and measurement of the integrated luminosity. Shape systematics include: lepton momentum calibration, modeling of the transverse momentum of bosons (W, Z, WW, and H), jet reconstruction efficiency, and jet energy scale calibration.

Fig. 1(c) presents, as a function of m_H, the upper limit on the cross section for the SM Higgs boson production. The limit is reported at 95% confidence level as a ratio to the predicted SM cross section. This study reaches its maximum sensitivity for $m_H = 165$ GeV, where the observed upper limit is 1.55 times the SM prediction.

5 Conclusions

We perform a search for the SM Higgs boson using a 5.4 fb^{-1} dataset of proton-antiproton collisions recorded with the D0 detector at the Fermilab Tevatron collider. We look for signal candidates by selecting events that have missing transverse energy and two oppositely charged leptons (e^+e^-, $e^\pm\mu^\mp$, or $\mu^+\mu^-$) with high transverse momenta. A Neural Network discriminant is used to separate signal candidate events from background. No significant excess of signal events is observed above the predicted background. Limits on the SM cross section for the production of a Higgs boson are set and provide one of the most stringent constraints on SM predictions. For a heavy Higgs boson ($m_H = 165$ GeV), the production cross section is determined to be less than 1.55 times the SM prediction with a 95% confidence level.

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