PROCEEDINGS OF SCIENCE

# Searches for High Mass Higgs at the Tevatron: $WW^{*}$ Final States

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We present searches for standard model Higgs production in p-pbar collisions at $\sqrt{s} = 1.96$ TeV using the latest amount of data collected by the CDF and D0 detectors at the Fermilab Tevatron. We consider the diboson decay channel $H \to W^{+}W^{-}$, the dominant decay mode for Higgs boson masses above 140 GeV/$c^{2}$. We also require that both W bosons decay leptonically. In order to maximize sensitivity, a combined matrix element method and neural network approach is used to distinguish signal from the large backgrounds. All Higgs production modes are considered, and cross-section limits relative to the combined standard model predictions are presented. In addition, searches for the Standard Model Higgs boson produced via the $W^{\pm}H \to W^{\pm}W^{+}W^{-}$ process are presented.

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## 1. Introduction

One of the cornerstones of how we understand electroweak symmetry breaking in the standard model (SM) rests on the existence of the Higgs boson, which in the SM provides the mechanism by which particles acquire mass. This striking feature of the SM has neither been observed nor completely ruled out. It is the only fundamental particle predicted by the SM which has yet to be observed.

In the SM the couplings of this Higgs boson to other particles is completely specified and is a function of the mass of the Higgs boson ($m_H$), which itself is unspecified. Direct searches at LEP give a lower limit on $m_H$ of 114.4 GeV/$c^2$ [1]. Indirect constraints from precision electroweak measurements indicate that the Higgs mass is likely less than 160 GeV/$c^2$ [2]. When the two are combined the upper limit increases to 191 GeV/$c^2$.

For $m_H > 135$ GeV/$c^2$ the Higgs boson predominantly decays to $W$-boson pairs. Both CDF and D0 search for the decay $H \rightarrow W^+W^-$ in the range $110 < m_H < 200$ where the final state consists of 2 charged leptons $+X$ [3, 4, 5]. All relevant production mechanisms ($gg \rightarrow H$, $WH$, $ZH$, $qq \rightarrow qqH$) are used in the analyses described here.

## 2. Experimental Apparatus

The CDF and D0 detectors are described in detail elsewhere [6, 7]. The analyses described here generally makes use of charged particle tracking spectrometers, calorimetry, muon detectors in the outermost portions of the detector, and high-$p_T$ lepton triggers from the respective online triggering systems. Shown here are analysis from CDF and D0 using 4.8 and 4.2 fb$^{-1}$ respectively.

## 3. Signal and Background

The final state of interest in these analyses involve two high-$p_T$ charged leptons and and a net energy imbalance due to the undetected neutrinos from leptonic decays of $W$ bosons. The largest background tends to be from Drell-Yan production where the large production rates combined with imperfect measurements of lepton momenta and hadronic portion of the event results in a non-trivial amount of such events passing a requirement on the missing transverse energy, though it is largely suppressed by this requirement and typically classified as non-Higgs-like by a neural network. Other backgrounds involving high-$p_T$ leptons include diboson production ($WW$, $WZ$, $ZZ$) and top pair production ($t\bar{t}$). Both $W+$jets and multi-jet production will will enter into the final sample due to the misidentification of hadronic jets as charged leptons. $W\gamma$ will also enter the sample when the photon is misidentified as a charged lepton (typically an electron from conversion). An example of the distribution of these backgrounds is shown in figure 1 for di-electron events for the D0 analysis after pre-selection (described below).

## 4. Event Selection and Analysis

The D0 analyses begins with the careful selection of dilepton candidates. The analyses described consist of a total of four channels: $e^+e^-$, $e^\pm\mu^\mp$, $\mu^+\mu^-$, and one channel containing

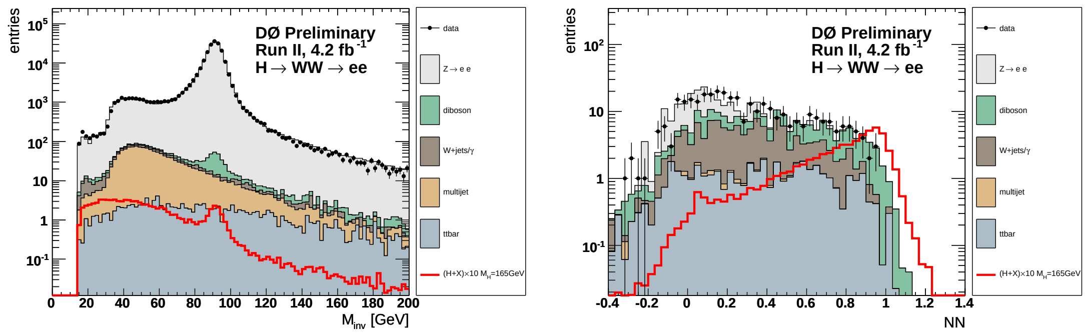


**Figure 1:** Example of signal and background for the D0 *ee* analysis showing the di-electron invariant mass at pre-selection (*left*) and the neural network output after all selection has been applied (*right*).

like-charge leptons. Events are first selected with a minimal amount of requirements (denoted as pre-selection) on lepton $p_T$ ($p_T > 15$ GeV or $p_T > 10$ GeV for the muon or second muon in the $e\mu$ and $\mu\mu$ channels respectively), dilepton invariant mass ($M_{\ell\ell} > 15$ GeV/$c^2$), and in the case of the $\mu^+\mu^-$ channel a requirement is also placed on the number of reconstructed jets ($N_{jet} < 2$) as well as the requirement that reconstructed jets are well isolated from the reconstructed muons ($\Delta R(\mu, jet) > 0.1$). The dilepton invariant mass at pre-selection is shown for the *ee* channel in figure 1.

The final event selection includes further requirements on several quantities related to the missing transverse energy (described in detail in Ref. [3]), transverse mass of the dilepton pair, azimuthal separation between leptons, and in the case of the $\mu^+\mu^-$ channel further requirements on the number and energy of reconstructed jets.

The CDF analysis similarly investigates events containing 2 high-$p_T$ leptons ($e$ or $\mu$) which have significant missing transverse energy as is expected in the decay $H \to WW$. The CDF analysis consists of four main channels. There are three channels for opposite-charge dilepton candidates which are constructed using the number of reconstructed jets in an event ($N_{jet} = 0$, $N_{jet} = 1$, and $N_{jet} \geq 2$. Only the gluon fusion process is considered in the 0-jet analysis. The other production processes ($WH$, $ZH$, and $qq \to qqH$) are included for events containing at least 1 jet where these processes contribute significantly. The fourth channel consists of like-charge dileptons where the signal considered is from both $WH$ and $ZH$ where one would expect to find real like-charge dilepton pairs.

Both CDF and D0 use neural network output as the final discriminant. A neural network is trained separately for each channel at each mass using several variables which have been optimized for each individual channel. An example of one of these variables is a matrix element based likelihood ratio used by CDF shown in figure 2. Once the networks have been trained templates are created for each signal and background which are used to place upper limits on SM Higgs production.

## 5. Results

CDF and D0 set upper limits on SM Higgs production in the mass range of $110 \leq m_H \leq 200$

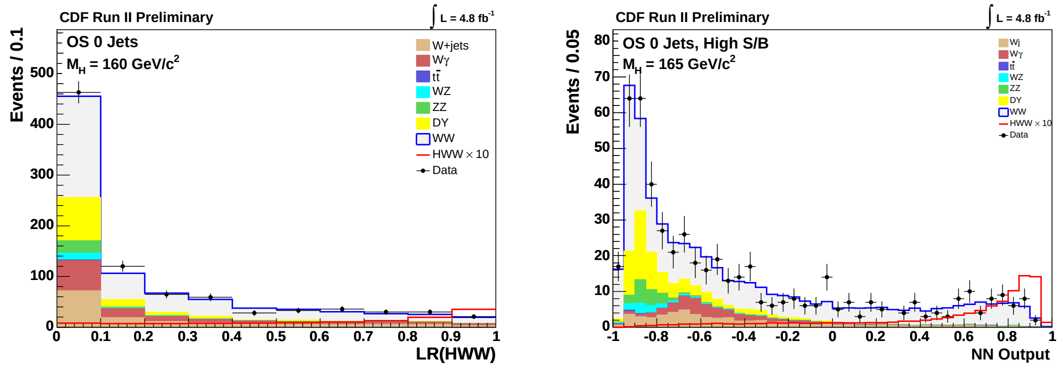


**Figure 2:** Matrix element based likelihood ratio used in the CDF 0-jet analysis (*left*) and neural network output example from the 0-jet channel CDF analysis (*right*).

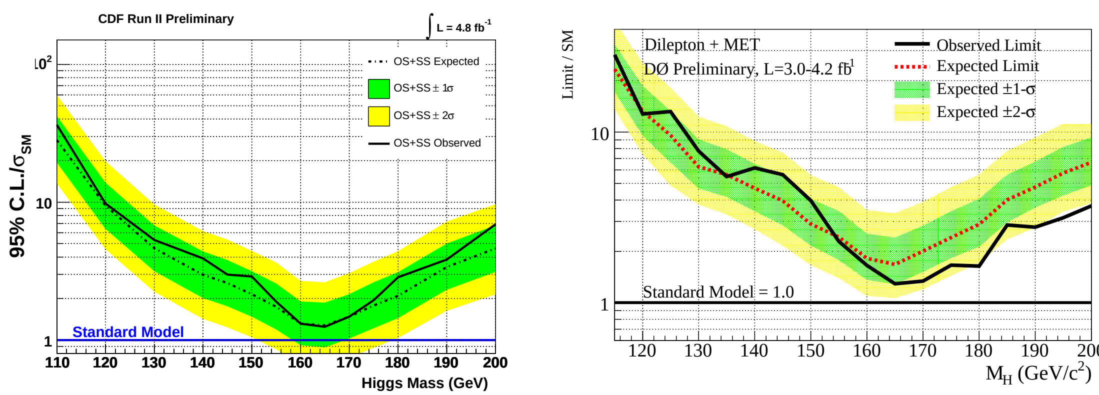


**Figure 3:** Upper limits on SM Higgs production as a function of the Higgs mass for the CDF (*left*) and D0 (*right*) analysis. Limits are quoted at 95% and are shown as a ratio to the expected SM production. The solid line is the observed limit. The dashed line and colored bands represent the expected limit and the $\pm 1\sigma$ and $2\sigma$ variations.

GeV/$c^2$. These limits are shown as a function of the Higgs mass in figure 3. Additionally, it should be noted that many systematic uncertainties are considered by both experiments which include both rate as well as shape uncertainties. These systematics are described further in Refs. [3, 4, 5].

## References


[1] ALEPH Collaboration and DELPHI Collaboration and L3 Collaboration and OPAL Collaboration and The LEP Working Group for Higgs Boson Searches, *Physics Letters B*, 565(17):61-75, 2003

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