Abstract. We report on direct searches for Higgs bosons carried out by the CDF and DØ Collaborations in proton-antiproton collisions at a center-of-mass energy of 1.96 TeV. Limits on the production cross section times branching fraction will be presented and a brief discussion of searches for supersymmetric Higgs bosons will be given. We will focus mainly on recent results only (those released in 2006), based on data sets of $260 - 950 \text{ fb}^{-1}$ of data collected between 2004 – 2006.

Keywords: Higgs boson


INTRODUCTION

The origin of electroweak symmetry breaking in the standard model is the Higgs mechanism in which a complex scalar doublet field gives rise to the masses of the $W$ and $Z$ bosons and results in a scalar particle known as the Higgs boson. The mass of the Higgs boson is not predicted by the theory, but is constrained by experiment. Searches at LEP II exclude a SM Higgs mass below 114.4 GeV/$c^2$ at the 95% C.L. Fits to the electroweak data provide an indirect constraint on the mass of the Higgs boson as described in the talk by Jens Erler at this conference [1]. The current limit is $M_H < 185 \text{ GeV}/c^2$ at the 95% C.L. when the LEP II direct limit is also included.

In this paper we describe recent results obtained at the Fermilab Tevatron by the CDF and DØ Collaborations based on data sets of $260 - 950 \text{ fb}^{-1}$ of proton–antiproton collisions at a center-of-mass energy of 1.96 TeV collected between 2004 – 2006. Future running is expected to yield 4–8 fb$^{-1}$ by the end of 2009.

The main search modes for a SM Higgs boson at the Tevatron are though the gluon-gluon fusion process and the $HV$ ($V = W$ or $Z$) associated production mechanism. The cross sections for these processes in the Higgs mass range of interest ($115 - 200 \text{ GeV}/c^2$) are $\sigma \sim 0.1 - 1.0 \text{ pb}$ for $gg$ fusion and $\sigma \sim 0.01 - 0.1 \text{ pb}$ for $HV$ associated production. The decay mode of the Higgs boson depends on its mass. For a low mass Higgs boson ($M_H \lesssim 130 \text{ GeV}/c^2$) $HV$ associated production with the Higgs decaying to $bb$ is the optimal search channel, while for higher masses $gg$ fusion with the Higgs decaying to $WW^*$ (with subsequent decay $WW^* \rightarrow \ell\nu\ell\nu$) is used. For intermediate masses $HV$ production with $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ is also sensitive.

1 For the CDF and DØ Collaborations
SEARCHES FOR THE STANDARD MODEL HIGGS BOSON

Both CDF and DØ have searched for a SM Higgs boson in the $WH \rightarrow \ell\nu b\bar{b}$ channel. The DØ results are from a data set of 378 pb$^{-1}$ while CDF have analyzed 695 pb$^{-1}$. An isolated electron or muon is selected with $p_T > 20$ GeV/c and missing transverse energy $E_T > 20 (25)$ GeV is required by CDF (DØ). In both cases two high-$p_T$ jets are required and $b$-jet tagging is applied using impact parameter or secondary vertex tagging. DØ separate the samples into single and double $b$-tagged samples, while CDF require one jet to be tagged with a neural-network $b$-tagger or two jets to be tagged with a vertex tagger. In both cases results are combined at the end. The DØ dijet mass distribution for the $W + 2 b$-tag sample is shown in Fig. 1. No evidence for a Higgs signal is found by CDF or DØ. Using a sliding search window of $\pm 25$ GeV/c$^2$ (DØ) or a binned maximum likelihood fit to the dijet mass distribution (CDF), limits are set on the cross section times branching fraction $\sigma(p\bar{p} \rightarrow WH) \times Br(H \rightarrow b\bar{b})$ as a function of Higgs mass. Results from CDF are shown in Fig. 1. The 95% C.L. limits from DØ are in the range $2.4 - 2.9$ pb for $M_H = 105 - 145$ GeV/c$^2$.

CDF and DØ have also searched for the Higgs boson in the $ZH \rightarrow \nu\bar{\nu} b\bar{b}$ channel, where the selection is based on large missing $E_T$ and two high-$p_T$ jets. CDF have analyzed 289 pb$^{-1}$ of data and require one or more of the jets to be $b$-tagged. DØ’s analysis is based on 261 pb$^{-1}$ and they split the data into samples with one and two $b$-tags, combining the results at the end. Figure 2 shows the DØ dijet invariant mass distribution for the $2 b$-tag analysis. Both collaborations set limits on the cross section times branching fraction as shown in the same Figure.

For Higgs boson masses above about 130 GeV the decay to $WW^*$ becomes dominant and the favored search channel is $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$. CDF and DØ have both searched in this channel with each $W$ decaying to either an electron or muon, resulting in three distinct channels: $ee$, $\mu\mu$, and $e\mu$. Two isolated, oppositely charged, high-$p_T$ leptons are required together with large missing $E_T$. Due to the spin-0 nature of the Higgs boson, the $H \rightarrow WW^*$ decay results in a small azimuthal angular separation between the two charged leptons ($\Delta\phi_{\ell\ell'} \sim 0$) and consequently a small dilepton invariant mass.
FIGURE 2. DØ dijet invariant mass distribution for $W^+ \geq 2$ b-tagged jets sample (left). 95% C.L. limits on the cross section times branching fraction as a function of Higgs mass (right).

$(m_{\ell\ell} \lesssim M_H/2)$. This is utilized to reject SM background, for example, DØ requires $\Delta \phi_{\ell\ell} < 0.2$ and $m_{\ell\ell} < M_H/2$. A likelihood fit to the dilepton azimuthal separation (shown in Fig. 3) is used to set limits on the cross section times branching fraction. Results from DØ are shown in Fig. 3.

FIGURE 3. Distribution of the azimuthal separation between the electron and muon in the DØ search for $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ (left). DØ 95% C.L. limits on the cross section times branching fraction $\sigma(pp \rightarrow H) \times Br(H \rightarrow WW^*)$ as a function of Higgs mass (right).

The process $WH \rightarrow WWW^*$ with leptonic decays of the $W$’s has been utilized by CDF and DØ to search for an intermediate mass Higgs. Events must contain a like-sign charged lepton pair, one from the “prompt” $W$ and one from a $W$ boson from the $H \rightarrow WW^*$ decay. A CDF analysis from 2004 used a data set of 194 pb$^{-1}$, while DØ has recently analyzed a data set of approximately 375 pb$^{-1}$. The DØ dilepton invariant mass distribution of selected like-sign and unlike-sign events is shown in Fig. 4. The number of like-sign events is consistent with SM backgrounds and charge sign mismeasurement in the detector. Limits on the cross section times branching fraction are shown in Fig. 4.

The Tevatron search results for the SM Higgs boson are summarized in Fig. 5 where the ratio of the 95% C.L. limit on $\sigma \cdot Br$ to the SM expected $\sigma \cdot Br$ is plotted as a function of Higgs boson mass. Efforts at combining results have begun, with DØ providing the
As can be seen the limits are generally at the level of a factor of approximately 10 higher than the SM prediction. It is estimated that the sensitivity predicted in the 2003 Tevatron Higgs sensitivity study [2] could be achieved once more data are collected, more search channels are added, CDF and DØ results are combined, and the analyses are refined (e.g. use of multivariate techniques, neural network b-tagging, improvements in the dijet mass resolution.)
SEARCHES FOR MSSM HIGGS BOSONS

In the minimal supersymmetric model (MSSM) there are two Higgs doublets leading to five physical Higgs bosons denoted $h, H, A, H^+, H^-$. In the MSSM an upper limit on the lightest Higgs of $M_{h_{\text{max}}} \approx 135 \text{ GeV}/c^2$ arises because, unlike in the SM, the Higgs self-couplings are related to the electroweak gauge couplings. The MSSM Higgs sector is described by two independent parameters at tree level, usually taken to be $M_A$ (the mass of the $A$) and $\tan \beta$ (the ratio of the vacuum expectation values of the two Higgs doublets). Important neutral Higgs production modes at the Tevatron are $gg, \bar{b}b \to \Phi (\Phi = h, H, A), \Phi b(\bar{b})$ production, and $hV, HV$ production with $V = W, Z$. The Higgs decay mode depends on $M_A$ and $\tan \beta$. For $M_A \gg M_Z$ and large supersymmetric particle masses, the $h$ decays are approximately the same as for a SM Higgs and the SM searches can be reinterpreted in terms of the MSSM. Decays of the $h$ and $H$ to $b\bar{b}$ are enhanced for large $\tan \beta$ (i.e. $\tan \beta \gg 1$). A large part of the MSSM parameter space is expected to be excluded at the 95% C.L. by the Tevatron with $\sim 5 \text{ fb}^{-1}$ of data [3].

DØ has performed a search for $\Phi b(\bar{b})$ production in the $\Phi \to b\bar{b}$ decay mode. Three or more $b$-tagged jets are required. The dijet invariant mass distribution (using the leading two $b$-tagged jets) is searched using a sliding mass window. Both CDF and DØ have searched for $\Phi$ production with $\Phi \to \tau\tau \to e\tau, \mu\tau$, or $e\mu$, where $\tau_h$ indicates a hadronic $\tau$ decay. The mass distribution of the visible $\tau$ decay products and the missing $E_T$ is used to set limits on the MSSM parameters. Figure 6 shows the 95% C.L. exclusion regions in the $M_A - \tan \beta$ plane. Also shown are the projections for the $\Phi \to \tau\tau$ search expected with larger data sets.

![Figure 6](image_url)

**FIGURE 6.** MSSM exclusion regions at the 95% C.L. in the $M_A - \tan \beta$ plane from DØ and CDF searches for $p\bar{p} \to \Phi b(\bar{b})$ with $\Phi \to bb$ and $p\bar{p} \to \Phi \to \tau\tau$. Also shown are the projections for the $\Phi \to \tau\tau$ search expected with larger data sets.

REFERENCES

1. J. Erler, *Fits to Electroweak Precision Data*, these proceedings.