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Search for Higgs at CDF

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Abstract. We present the results on the searches for the SM and the non-SM Higgs boson production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV with the CDF detector at the Fermilab Tevatron. Using data corresponding to 300–700 pb^{-1}, we search for the Higgs boson in various production and decay channels. No signal is observed, therefore, we set upper limits on the production cross-section times branching fraction as a function of the Higgs boson mass.

Keywords: Higgs, CDF, electroweak, standard model, doubly-charged
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INTRODUCTION

In the standard model (SM), the Higgs mechanism provides masses to fundamental particles via electroweak symmetry breaking, which requires the existence of a scalar, neutral particle: the Higgs boson. However, several open issues of SM, such as the fine tuning required to keep the quadratic radiative correction to the Higgs boson mass under control (hierarchy problem), suggest extensions of the SM. In many SM extensions, such as the supersymmetric model (SUSY), the left-right symmetric model, and the little Higgs model, there is a richer Higgs spectrum with additional neutral, charged, and doubly-charged Higgs bosons. Using data corresponding to an integrated luminosity of 300–700 pb^{-1}, CDF has searched for the SM Higgs and the doubly-charged Higgs boson in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron. All the searches include charge conjugate decays.

SEARCH FOR STANDARD MODEL HIGGS

Combining the results on the direct searches at LEP and the precision SM fits of electroweak data (excluding the low energy data), the mass of the SM Higgs boson is bounded in the range: 114.4–199 GeV$/c^2$ at 95% CL [1]. At the Tevatron, the SM Higgs is mainly produced through gluon fusion with a cross-section of 0.1–1 pb. This direct production is 1–2 orders of magnitude larger than the associated Higgs production, where the Higgs is produced with a Z^0, a $W^{\pm}$, or a $t\bar{t}$ pair. For M_H>130 GeV$/c^2$, SM Higgs primarily decays into W^+W^-, and can be searched for cleanly in the gluon-fusion channel, using the final state with two leptons and missing transverse [2] energy ($\not\!\!E_T$). However, for M_H<130 GeV$/c^2$, the dominant decay mode is $H \to bb$, and must be searched for in the associated production channel to suppress background from the direct production of heavy-flavor jets. The following subsections describe searches for the SM Higgs in three different production and decay channels.

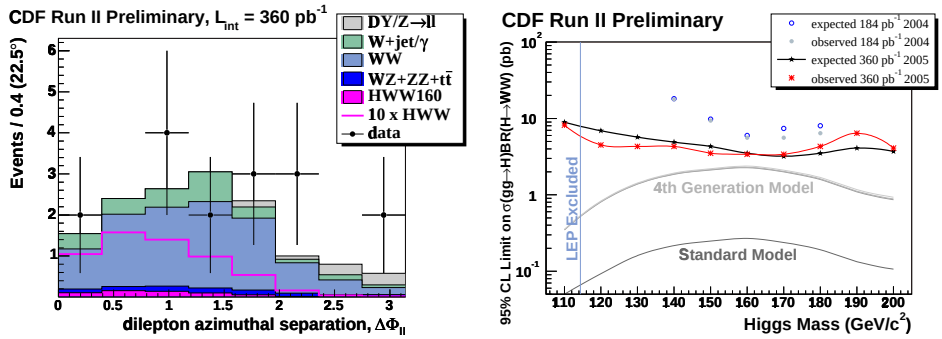

FIGURE 1. The $\Delta\phi_{\ell\ell}$ distributions from data and the SM prediction assuming M_H=160 GeV$/c^2$ (left) and the expected and observed upper limits as a function of M_H (right).

Search for $H \to W^+W^- \to \ell^+\ell^-\nu_\ell\bar{\nu}_\ell$

This search [3] selects events with $\not\!\!E_T > \frac{M_H}{4}$ GeV and two opposite-sign isolated leptons (e or μ) with p_T^1>20 and p_T^2>10 GeV$/c$. The decay of the spin-0 Higgs into WW prefers a small azimuthal angle between the two leptons ($\Delta\phi_{\ell\ell}$), a small dilepton invariant mass ($M_{\ell\ell}$), and large $\not\!\!E_T$, and provides a good discriminant between signal and the SM backgrounds, especially the W^+W^- production. In order to suppress backgrounds from $c\bar{c}$, $b\bar{b}$ resonances, Drell-Yan, $Z \to \tau^+\tau^-$, and mis-measured $\not\!\!E_T$ in addition to the SM diboson production, analysis requirements are applied on: $M_{\ell\ell}$ and p_T^1+p_T^2+$\not\!\!E_T$ as a function of M_H, and the angle between $\not\!\!E_T$ and the closest jet or lepton. Events with $\geq$1 energetic jets are also removed to reduce the $t\bar{t}$ background. With no evidence of a Higgs signal, a 95% CL upper limit on production times branching fraction is set as a function of M_H, by comparing the $\Delta\phi_{\ell\ell}$ distribution in data against that from the SM prediction (see Fig. 1). For M_H=160 GeV$/c^2$, the upper limit on $\sigma(gg \to H)\mathscr{B}(H \to WW)$ is 3.2 pb.

Search for $W^+H \to \ell^+\nu_\ell b\bar{b}$

This analysis [4] selects events with $\not\!\!E_T$>20 GeV, one isolated lepton (e or μ) with p_T>20 GeV$/c$, and two jets with E_T>15 GeV, $|\eta|$<2, where $\geq$1 jet must be selected by the CDF secondary vertex (SecVtx) [5, 6] and the neural network (NN) b-tagging algorithms. The NN has been developed to further reduce 50% of the c-jet and 65% of the light-flavor jet backgrounds while retaining 90% of the b-jet signal after SecVtx is performed. Additional requirements are applied to veto the Drell-Yan and $t\bar{t}$ backgrounds. The dominant background after b-tagging arises from the SM $Wb\bar{b}$ production. Events after selection are separated into two classes: 1. only one jet tagged by both SecVtx and NN, 2. two jets tagged by SecVtx. By treating these two classes of events as independent measurements and combining their results later, the sensitivity is increased by $\sim$20 % with respect to that from the inclusive $\geq$1 b-tagged events. The dijet mass distribution forms a discriminant between signal and the SM backgrounds, and an upper limit on $\sigma(p\bar{p} \to WH)\mathscr{B}(H \to b\bar{b})$ is set as a function of M_H (see Fig. 2). For a Higgs boson mass near the LEP lower limit, M_H=115 GeV$/c^2$, the upper limit is 3.6 pb.

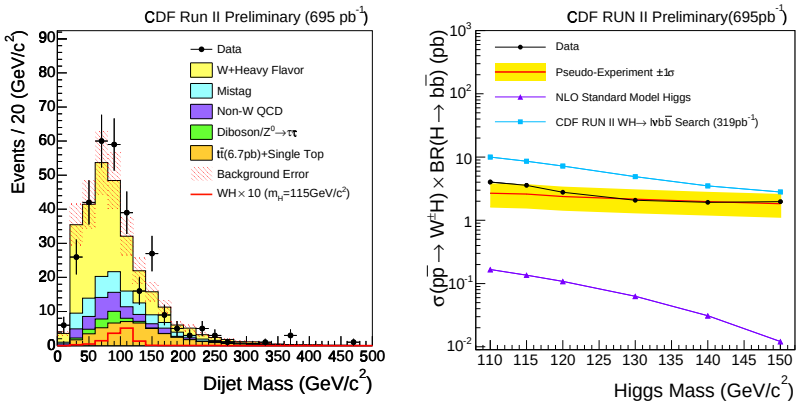

FIGURE 2. The dijet mass distributions from data and the SM prediction for events with only one jet tagged by SecVtx and NN, assuming M_H=115 GeV$/c^2$ (left) and the expected and observed upper limits as a function of M_H (right).

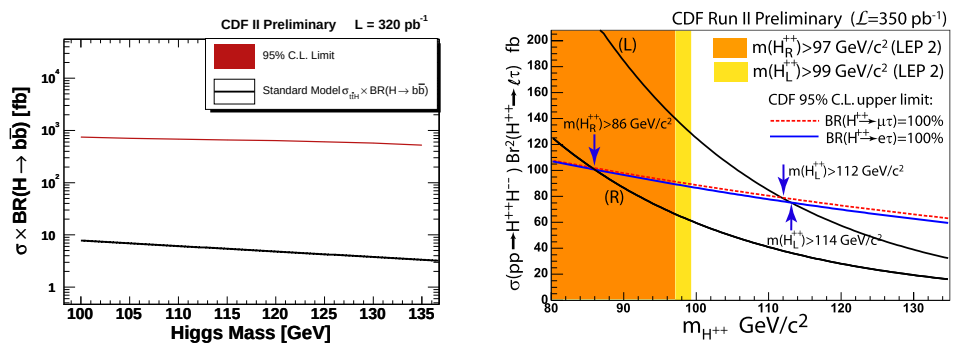

FIGURE 3. The observed upper limits on production times branching fraction as a function of M_H for the $t\bar{t}H$ (left) and H^{++} (right) searches. The intersections of the theoretical predictions and the observed limits in the right figure give lower limits on the masses of left- and right-handed H^{++} bosons.

Search for $t\bar{t}H \to W^+W^-b\bar{b}b\bar{b} \to \ell^+\nu_\ell jjb\bar{b}b\bar{b}$

This search [7] selects events with $\not{E}_T$>10 GeV, one isolated lepton (e or μ) with p_T>20 GeV$/c$, and ≥5 jets with E_T>15 GeV, $|\eta|$<2, where ≥3 jets are tagged by SecVtx. The leading background is the SM direct production of $t\bar{t}b\bar{b}$ and $t\bar{t}c\bar{c}$ events. No signal is found for the Higgs, and an upper limit on $\sigma(p\bar{p} \to t\bar{t}H)\mathscr{B}(H \to b\bar{b})$ is set as a function of M_H (Fig. 3). For M_H=115 GeV$/c^2$, the upper limit is 660 fb. Although the observed limit is still ∼2 orders of magnitude larger than the SM prediction, this channel is one popular channel at LHC and provides a valuable input for the future search.

SEARCH FOR NON-SM DOUBLY-CHARGED HIGGS

Several extensions of SM predict the existence of the doubly-charged Higgs H^{++}. At the Tevatron, the main production mechanism is the pair production: $p\bar{p} \to \gamma^*/Z \to$

$H^{++}H^{--}$. For M_H<160 GeV/c^2, decays to W's are suppressed while decays to leptons are theoretically unrestricted including possible lepton-flavor violation. This analysis [8] searches for $H^{++} \to e^+\tau^+$, $\mu^+\tau^+$, which extends the previous CDF search for e and μ final states [9]. Analysis requires an e or a μ with p_T>20 GeV/c, a hadronically decaying τ with p_T>15 GeV/c, and $\geq$ 1 isolated track system which contains 1 or 3 tracks with $\sum p_T$>8 GeV/c. Events with 3 and 4 lepton candidates are treated as independent measurements. In order to reduce backgrounds from the SM Z+jet, diboson, and $t\bar{t}$ production, selection criteria on $M_{\ell\ell}^{OS}$ [10], $M_{\ell\ell}^{SS}$, and $\sum p_T^{\ell} + \not{E}_T$, are optimized for the 3-lepton and the 4-lepton events, respectively. The $\not{E}_T$ is also required to be at least 20 GeV for the 3-lepton events always and for the 4-lepton events only when $M_{\ell\ell}^{OS}$<120 GeV/c^2. With no excess, the observed upper limit on $\sigma(p\bar{p} \to H^{++}H^{--})\mathscr{B}^2(H^{++} \to \ell\tau)$ is used to extract a lower limit on $M_{H^{++}}$, assuming the left-right symmetric model and exclusive decays into $e\tau$ and $\mu\tau$. The lower limits on the mass of the left-handed H^{++} boson supersede the limit set by the LEP experiments and are found to be: H_L^{++}>112 GeV/c^2 for the $\mu\tau$ and H_L^{++}>114 GeV/c^2 for the $e\tau$ final states, respectively.

CONCLUSION

CDF has searched for both the SM and non-SM Higgs bosons using 300–700 pb^{-1} of data. No evidence of Higgs boson production is found in the analyzed data, yet. As more data are being collected and more advanced analysis techniques are being developed, by combining the CDF results with those of D0, the Tevatron experiments have the potential to discover SM as well as non-SM Higgs.

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10. The superscript "OS" stands for opposite-sign dilepton pair, while "SS" stands for same-sign pair.