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 these 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 energy ($E_T$). However, for $M_H < 130$ GeV/$c^2$, the dominant decay mode is $H \rightarrow b\bar{b}$, 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.
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With respect to that from the inclusive
The NN has been developed to further reduce 50% of the
The dominant background after
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light-flavor jet backgrounds while retaining 90% of the
measurements and combining their results later, the sensitivity is increased by
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(see Fig. 1). For a Higgs boson
prefers a small azimuthal angle between the two leptons (Δφℓℓ), and large E_T, and provides a good discriminant between signal and the SM backgrounds, especially the
SM diboson production, analysis requirements are applied on:
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leptons (ℓ⁺ℓ⁻). The decay of the spin-0 Higgs into WW prefers a small azimuthal angle between the two leptons (Δφℓℓ), a small dilepton invariant mass (M_ℓℓ), and large 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¯c, b¯b resonances, Drell-Yan, Z → τ⁺τ⁻, and mis-measured E_T in addition to the SM diboson production, analysis requirements are applied on: M_ℓℓ and p_T^1+p_T^2+E_T as a function of M_H, and the angle between E_T and the closest jet or lepton. Events with ≥1 energetic jets are also removed to reduce the t¯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 Δφℓℓ distribution in data against that from the SM prediction (see Fig. 1). For M_H=160 GeV/c², the upper limit on σ(gg → H)BR(H → WW) is 3.2 pb.

Search for W⁺H → ℓ⁺νℓb¯b

This analysis [4] selects events with E_T>20 GeV, one isolated lepton (e or µ) with
p_T>20 GeV/c, and two jets with E_T>15 GeV, |η|<2, where ≥1 jet must be selected
by the CDF secondary vertex (SecVtx), 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¯t backgrounds. The
dominant background after b-tagging arises from the SM Wb¯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 ~20% with
respect to that from the inclusive ≥1 b-tagged events. The dijet mass distribution
forms a discriminant between signal and the SM backgrounds, and an upper limit on
σ(p¯¯p → WH)BR(H → b¯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/c², the upper limit is 3.6 pb.

Search for H → W⁺W⁻ → ℓ⁺ℓ⁻νℓνℓ

This search [3] selects events with E_T>0.5M_H 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 (Δφℓℓ), a small dilepton invariant
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SM diboson production, analysis requirements are applied on: M_ℓℓ and p_T^1+p_T^2+E_T as a function of M_H, and the angle between E_T and the closest jet or lepton. Events with ≥1 energetic jets are also removed to reduce the t¯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 Δφℓℓ distribution in data against that from the SM prediction (see Fig. 1). For M_H=160 GeV/c², the upper limit on σ(gg → H)BR(H → WW) is 3.2 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 $t\bar{t}H \rightarrow W^+W^-b\bar{b}b\bar{b} \rightarrow \ell^+\nu\ell^-jbjb\bar{b}\bar{b}$

This search \[7\] selects events with $E_T>10$ GeV, one isolated lepton ($e$ or $\mu$) with $p_T>20$ GeV/$c$, and $\geq 5$ jets with $E_T>15$ GeV, $|\eta|<2$, where $\geq 3$ 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 $\sigma(p\bar{p} \rightarrow t\bar{t}H)\mathcal{B}(H \rightarrow b\bar{b})$ 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 $\sim 2$ 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: $p\bar{p} \rightarrow \gamma'/Z \rightarrow$
$H^{++}H^{--}$. 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 $H^{++} \rightarrow e^+\tau^+,\mu^+\tau^+$, which extends the previous CDF search for $e$ and $\mu$ final states [9]. Analysis requires an $e$ or a $\mu$ with $p_T > 20$ GeV/c, a hadronically decaying $\tau$ 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 $\sum p_T + \not{E}_T$ 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 $\sigma(p\bar{p} \rightarrow H^{++}H^{--})B^2(H^{++} \rightarrow \ell\tau)$ 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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