Searches for a low mass SM Higgs at the Tevatron

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We present recent results from the low mass standard model Higgs searches performed by the CDF and D experiments at the Tevatron pp collider operating at $\sqrt{s} = 1.96$ TeV. A low mass Higgs can be produced at the Tevatron in association with a $W/Z$ boson or directly through gluon-gluon or vector-boson fusion and will preferentially decay to a $b\bar{b}$, $\tau\tau$, or $\gamma\gamma$ pair. We present results from searches for these production and decay modes using between 1.0-4.2 fb$^{-1}$. Unfortunately, neither experiment finds evidence for the Higgs boson, thus, limits on the Higgs boson production rate for each mass hypothesis are presented both for the individual searches as well as the combined Tevatron limit.

1 Introduction

The Higgs boson is a massive electrically neutral spin-0 particle created when electroweak gauge symmetry is spontaneously broken as the vacuum acquires a non-zero expectation value. Previous searches for the Higgs boson by experiments at the LEP collider failed to find strong evidence for its existence, however conclude that its mass must be greater than 114.4 GeV/c$^2$ at 95% CL$^1$. Indirect constraints on the Higgs mass is also available through precision electroweak measurements. A recently updated analysis suggests the Higgs boson mass to be less than 163 GeV/c$^2$ at 95% CL$^2$.

Searches for a Higgs boson at the Tevatron are subdivided in two categories depending on the assumed mass. Low mass searches assume a Higgs mass ($m_H$) less than 135 GeV/c$^2$ and high mass searches assume $m_H > 135$ GeV/c$^2$. If the Higgs boson mass is low it will decay primarily into a $b\bar{b}$ ($\sim 80 - 90\%$ BR) or $\tau^+\tau^-$ pair ($\sim 7 - 8\%$ BR). The Higgs boson can also decay into a diphoton pair through a virtual loop with a branching ratio of 0.2%. All searches for a low mass Higgs at the Tevatron require one of these three final states.

In $pp$ collisions, the Higgs is produced primarily through gluon-gluon fusion via a virtual top quark loop with $\sigma(gg \rightarrow H) \approx 1$ pb for $m_H = 115$ GeV/c$^2$. The Higgs is also produced in association with a $W$ or $Z$ gauge boson with a slightly lower cross section, however these events produce highly boosted decay products which greatly reduces the overall background rate. Finally, with an even lower rate the Higgs is created through vector boson fusion producing a central Higgs decay and two forward jets.

This report summarizes the low mass Higgs searches by the CDF and D experiments. The following search channels are described in this note: $WH \rightarrow \ell\nu b\bar{b}$, $ZH \rightarrow \ell\bar{\ell}b\bar{b}$, $ZH \rightarrow \nu\bar{\nu} b\bar{b}$, and inclusive $H \rightarrow \tau\tau$ and $H \rightarrow \gamma\gamma$ decays. The combined Tevatron limits are presents following the individual results.
2 Recent Higgs Search Results

2.1 WH → ℓνbb Associated Higgs Production Search

The CDF and DØ experiments both search for WH associated Higgs production in the ℓνbb final state using 2.7 fb⁻¹. The event selection for this search requires one high \( p_T \) isolated lepton (electron or muon), large missing transverse energy to indicate the presence of a neutrino, and two high \( p_T \) jets. CDF also selects events with an isolated track if a lepton is not reconstructed. Since the Higgs decays to a \( bb \) pair in this analysis, both experiment rely heavily on \( b \)-jet tagging, which uses high impact parameter tracks within the jet cone radius to indicate the presence of a long-lived \( B \) hadron decay. CDF combines these tracks to form secondary (displaced) vertices as well as computing a jet lifetime, which is distinct for \( B \) decays and charm or other long-lived light flavor hadron decays. DØ combines information from the displaced decay vertex (e.g. vertex mass, track multiplicity) in a neural network whose shape for \( B \) decays tend towards one while light-flavor decays tend towards one, where a jet is considered “\( b \)-tagged” if its network output value is near one. Both analyses separate events by the number of tagged \( b \)-jets to maximize sensitivity. The dominant backgrounds after \( b \)-tagging are \( W \rightarrow \ell \nu + \) jets and top pair production, both of which can produce two \( b \)-jets in the final state.

Both experiments increase their search sensitivity through the use of multivariate analysis techniques. CDF employs three such techniques in their search. The first is a neural network method trained with WH signal against \( W + bb \) background. The second is a matrix element method which uses leading order matrix elements to define a signal and background event probability. The third method is a boosted decision tree algorithm that is trained using the matrix element probabilities as discriminating variables. These three algorithms are combined with the NEAT neural network algorithm. Using the shape of the NEAT output distribution for the expected signal, background, and data, this analysis excludes a production rate of 5.6 times the SM rate for a 115 GeV/c² Higgs mass. DØ also uses a neural network technique to separate signal and background and excludes a cross section of 6.7 times the SM prediction for the same Higgs mass. Both experiments report exclusions at 95% CL. The CDF and DØ multivariate output distributions are shown in Figure 1.

2.2 ZH → ℓℓbb Associated Higgs Production Search

The event signature for this search is two high \( p_T \) isolated leptons and two high \( p_T \) \( b \)-jets with the CDF search analyzing 2.7 fb⁻¹ while the DØ result is newly updated for this conference with 4.2 fb⁻¹. In addition to the increased data set, DØ has updated the event selection to include events with one isolated muon and one isolated track as well as events with one isolated
electron and one electron-like candidate that is reconstructed between the central and forward calorimeter cryostats. Both analyses also require one or more $b$-tagged jets in the event to reduce the $Z+\text{light flavor}$ background. In both searches the dominant backgrounds after $b$-tagging are $Z+\text{jets}$ and dilepton $t\bar{t}$ production.

Similar to the $WH$ search, both experiments employ multivariate techniques to isolate the $ZH$ signal. CDF uses its neural network distribution to set limits of $6.9$ times the SM prediction and $D\bar{O}$ uses its boosted decision tree output to set limits of $7.5$ in the same units each for $m_H = 115\text{ GeV}/c^2$. The two multivariate outputs for double tagged events are shown in Figure 3.

### 2.3 $ZH \rightarrow \nu\nu bb$ Associated Higgs Production Search

This search requires two high $p_T$ $b$-tagged jets as well as large missing transverse energy representing the two neutrinos produced in the $Z$ decay. Both experiments report results with $2.1\text{ fb}^{-1}$. The backgrounds in this channel are mainly QCD multijet production and $W+\text{jets}$ events when the lepton from the $W \rightarrow \ell\nu$ decay is not reconstructed. As with the $WH$ and $ZH$ searches, each experiment uses a multivariate technique to isolate the Higgs signal. CDF uses its neural network distribution to set limits of $6.9$ times the SM prediction and $D\bar{O}$ uses its boosted decision tree output to set limits of $7.5$ in the same units each for $m_H = 115\text{ GeV}/c^2$. The two multivariate outputs for double tagged events are shown in Figure 3.
2.4 Inclusive $H \rightarrow \tau \tau$ and $H \rightarrow \gamma \gamma$ Searches

Both CDF and DØ combine searches with one or more $\tau$ candidates in the final state to search for the Higgs. CDF recently completed an analysis with 2.0 fb$^{-1}$ in the inclusive $\tau\tau+X$ final state. In this channel, the Higgs may be produced in association with a $W/Z$ boson, directly through gluon-gluon fusion, or through vector boson fusion. This analysis uses a neural network trained against the large QCD multijet background as well as separate networks to discriminate $t\bar{t}$ and $Z \rightarrow \tau\tau$ events. Combining these networks, CDF excludes 31 times the SM prediction for $m_H = 115\text{ GeV}/c^2$. DØ combines their $WH \rightarrow \tau\nu b\bar{b}$ and inclusive $H \rightarrow \tau\tau + X$ analyses both using 1.1 fb$^{-1}$ setting limits of 27 times the SM prediction also for a 115 GeV/c$^2$ Higgs mass.

DØ recently updated a analysis with 4.2 fb$^{-1}$ searching for the Higgs boson decaying to a diphoton pair. The diphoton mass distribution is divided into $\pm 15\text{ GeV}$ mass windows surrounding the assumed Higgs mass and fit to the observed data resulting in a limit of 13 times the SM prediction for $m_H = 115\text{ GeV}/c^2$ Higgs mass.

3 Combined Higgs Mass Limits

Because no one Higgs search is sensitive to the SM predicted cross section all searches are combined to maximize sensitivity. Details of the statistical combination can be found in $^3$. By combining all available results, we expect to exclude a Higgs production cross section slightly below three times the SM prediction for all masses between 115 and 150 GeV/c$^2$. The observed value for $m_H = 115\text{ GeV}/c^2$ is 2.5 times the SM prediction.

Assuming each experiment collects 2-3 times the currently available integrated luminosity and all analyses incorporate expected improvements, the Tevatron hopes to exclude at 95% CL all Higgs masses 114 and 150 GeV/c$^2$ by the end of Run II. However, it is unlikely that a 3$\sigma$ evidence claim can be made with the full dataset if the Higgs mass is above 125 GeV/c$^2$ and below 145 GeV/c$^2$.

4 Summary

We have presented recent results from the low mass Higgs searches performed by the CDF and DØ experiments. Using up to 4.2 fb$^{-1}$ of Run II data, the combined limit on standard model Higgs production is 2.5 times the predicted value for a 115 GeV/c$^2$ Higgs keeping hope alive that a low mass Higgs may be seen or otherwise will be excluded by the combined Tevatron search in the near future.

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References

3. Information about the Tevatron combination can be found at the following website http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_09