Standard Model Higgs Searches at the Tevatron (Low Mass)

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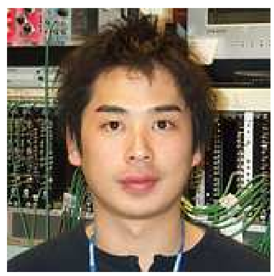


We present recent results of the Standard Model (SM) Higgs boson searches from the Collider Detector at Fermilab (CDF) and DØ experiments using 1.0-2.1 fb^{-1} data from proton-antiproton collisions with $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron. For Higgs mass (m_H) less than 135 GeV/c^2 (so-called low mass region), $W^{\pm}H \to l^{\pm}\nu b\bar{b}$, $ZH \to l^+l^- b\bar{b}$, and $ZH \to \nu\bar{\nu}b\bar{b}$ processes are the most sensitive channels and those results are summarized in this report. In addition, a new CDF search based on $H \to \tau^+\tau^- + 2jets$ mode is described. Both CDF and DØ have found no evidence for the Higgs boson, and therefore set upper limits on the Higgs production cross section. The latest Tevatron combined limits are also presented.

1 Introduction

The Higgs boson is an essential component in the Standard Model (SM), which provides masses to fundamental particles through electroweak symmetry breaking, but yet undiscovered as of now. Theory indicates that the Higgs should be a scalar and charge-neutral boson but no predictions on its mass. However, combining the results from the direct searches at LEP and the SM global fits based on electroweak data, the mass of the SM Higgs boson is bounded in the range of 114.4 to 144 GeV/c^2 at 95% confidence limit (CL) [1].

The CDF and DØ experiments at the Tevatron are currently the only places capable of searching for the Higgs boson. The dominant Higgs production mode at the Tevatron ($p\bar{p}$ collision with $\sqrt{s} = 1.96$ TeV) is via gluon fusion ($\sigma =\sim 1$ pb) which is about five to even ten times larger than the associated production of $W^{\pm}H$ and ZH. The fourth highest production is given by so-called Vector Boson Fusion (VBF) process with slightly lower production rate than ZH. In the low mass region ($m_H < 135$ GeV/c^2), the Higgs immediately decays to $b\bar{b}$ at 70$\sim$80% or $\tau^+\tau^-$ at 7$\sim$8% respectively. Although $gg \to H \to b\bar{b}$ mode is expected to provide the largest signal yield, it is overwhelmed by QCD multijet background. Therefore the most relevant channels at the Tevatron are $W^{\pm}H \rightarrow l^{\pm}\nu b\bar{b}$, $ZH \rightarrow l^{+}l^{-}b\bar{b}$, and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ as shown in figure 1.

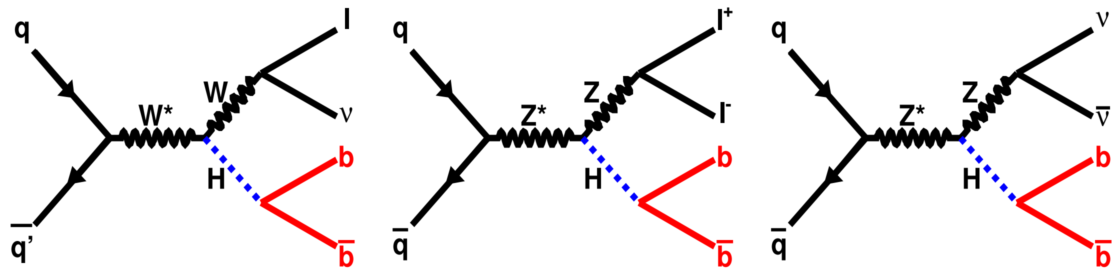


Figure 1: Tree level Feynman diagrams for signal processes used for low mass Higgs searches: From left to right, $W^{\pm}H \rightarrow l^{\pm}\nu b\bar{b}$, $ZH \rightarrow l^{+}l^{-}b\bar{b}$, and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ final states.

In addition to these channels, CDF newly performed the SM Higgs boson search using $H \rightarrow \tau^{+}\tau^{-} + 2jets$ from WH, ZH, VBF, and gluon fusion processes. In this report, all results and combined limits are briefly summarized.

2 Recent RunII Results

Both CDF and DØ have established the search for the SM Higgs as one of their highest priorities and already presented elsewhere and published (*e.g.* in [2]). This proceeding therefore mainly focuses on describing recent updates for analyzes with 1.0∼2.1 fb^{-1} of data, depending on channels.

For $H \rightarrow b\bar{b}$ associated with W/Z boson, b quark identification is one of the key elements in event selection. b quarks produce jets in detection and can be identified by either secondary vertex algorithm (SecVtx btagging) or jet probability algorithm (JetProb btagging) based on the large B hadron lifetime. The former algorithm looks for a displaced vertex from the primary vertex of an event [2,3] while the latter requires a low probability that all tracks contained in a jet originated from the primary vertex, based on the track impact parameters [3]. These btagging requirements are crucial to reduce large $W/Z + jets$ and QCD multijet backgrounds where non-$bjet$ (gluon jet and $u-, d-, c-, s-$ jets) contribution is dominated. However since the Higgs signal is still much smaller than the backgrounds even after btagging, all analyzes presented here employed multivariate techniques (Artificial Neural Net (ANN) or Boosted Decision Tree (BDT)) to further improve signal-to-background ratio.

Although significant improvements with enormous efforts have been achieved by both CDF and DØ, no single analysis by itself would reach the sensitivity needed for discovery or exclusion. Thus all channels studied must be combined.

2.1 Search for $W^{\pm}H \rightarrow l^{\pm}\nu b\bar{b}$

The event selection is imposed by having one high p_T isolated lepton (e or μ), missing transverse energy ($\not{E}_T$) from the neutrino (from W decay), and two or more jets (exact two jets in CDF) expected from Higgs decay. CDF and DØ results presented here are based on 1.9 fb^{-1} and 1.7 fb^{-1} data respectively. From previous results, CDF updated the analysis to include forward electron with η up to ∼2.0 and also added 1 $btag$ category with neural net flavor separation (ANN$_{btag}$) in addition to double btagged events [3]. Candidate events are therefore classified into three categories: 2 SecVtx, 1 SecVtx + 1 JetProb, and 1 ANN$_{btag}$. Those three are exclusive to each other and have different signal purity. Thus they are analyzed separately but combined to obtain the final sensitivity in the likelihood calculation. DØ uses events with not only exact two jets but also three jets and performed sample splitting in a similar way of CDF (1 ANN *tight* bjet and 2 *loose* ANN bjets, depending on operation point with respect to fake rate and signal efficiency where they have been selected based on the optimal combined sensitivity to a WH signal) [4]. Dominant backgrounds are $W + b\bar{b}$ and $t\bar{t}$ events. Both CDF and DØ use ANN technique for the final fit to distinguish signal from such backgrounds. Figure 2 shows ANN output distribution (CDF) and dijet mass distribution (DØ) for 2 btagged events. No significant excess is observed, so upper cross section limits at 95% CL are set. For $m_H = 115$ GeV/c^2, DØ sets a limit of 1.4 pb (1.2 pb expected) and CDF sets a limit of 1.1 pb (1.0 pb expected) while SM prediction on $\sigma(p\bar{p} \to WH) \times BR(H \to b\bar{b})$ is 0.13 pb.

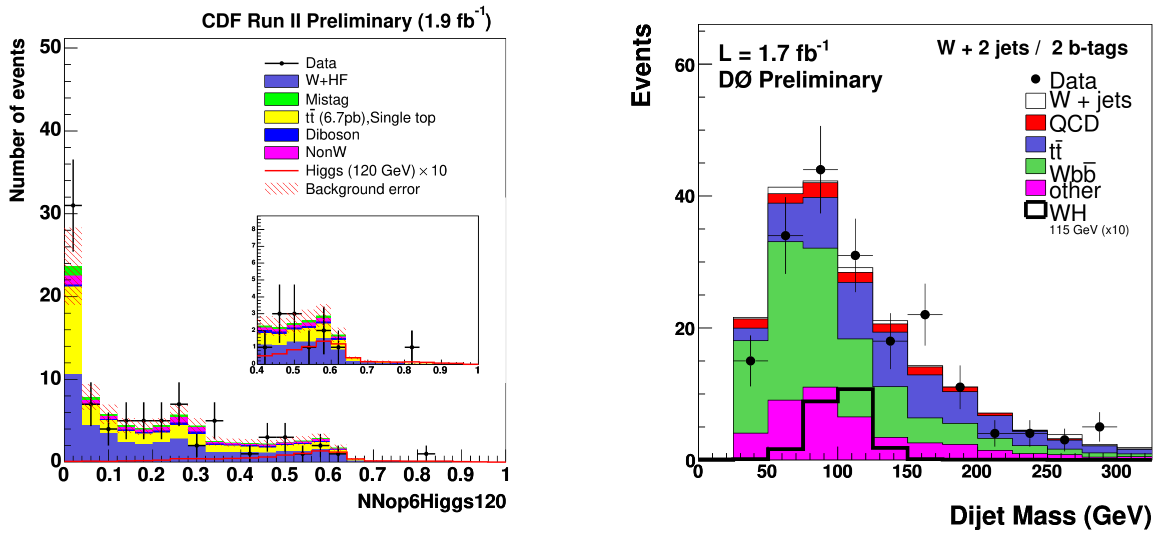


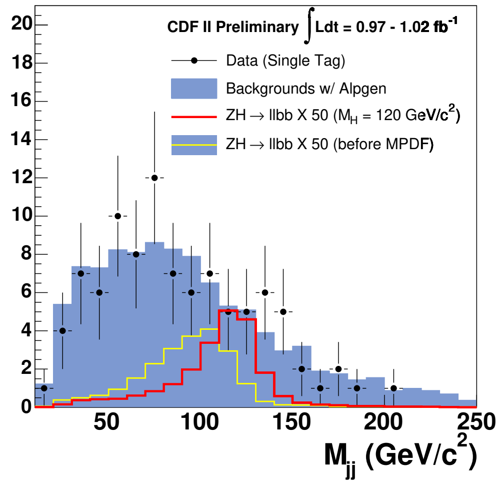
Figure 2: Left: ANN distribution from CDF. Right: Dijet mass distribution from DØ. Both are for events with 2 btagged jets. Higgs signal (times 10) is also shown for comparison.

2.2 *Search for* $ZH \to l^+l^-b\bar{b}$

Since this analysis was done in Summer 2007 based on relatively small data (1.0-1.1 fb^{-1}) compared to other analyzes summarized in this proceeding, only core parts of the analysis are briefly described here. More details can be found elsewhere [5,6]. The signature for this channel is two high p_T isolated leptons and two hight E_T jets that could be identified as b jets. The main backgrounds are $Z + jets$ with mis-btagging, $Z + b\bar{b}$ and $t\bar{t}$. DØ uses one dimensional ANN with ten kinematic variables while CDF's ANN analysis is two dimensions with eight variables to distinguish signal from $Z + jets$ and $t\bar{t}$ separately. CDF also employed ANN to improve the energy resolution of dijet invariant mass by correcting energies of two leading jets independently according to their projection onto the $\not\!\!E_T$ direction. This correction improves dijet mass resolution from 14% to 9% as shown in figure 3. No excess is found in signal region and so for $m_H = 115$ GeV/c^2, DØ sets a limit of 1.4 pb (1.6 pb expected) and CDF sets a limit of 1.3 pb (1.3 pb expected) while SM prediction on $\sigma(p\bar{p} \to ZH) \times BR(H \to b\bar{b})$ is 0.8 pb.

2.3 *Search for* $ZH \to \nu\bar{\nu}b\bar{b}$

In this channel, there is no leptons in the final state and so the signature is two high E_T jets which could be btagged and high $\not\!\!E_T$ due to the two neutrinos from Z decay. The main backgrounds arise from $Z + jets$, $Z + b\bar{b}$, $t\bar{t}$, and QCD. This analysis is challenging because except for $Z \to \nu\bar{\nu} + b\bar{b}$, all backgrounds are basically fakes originated from either mis-btagged



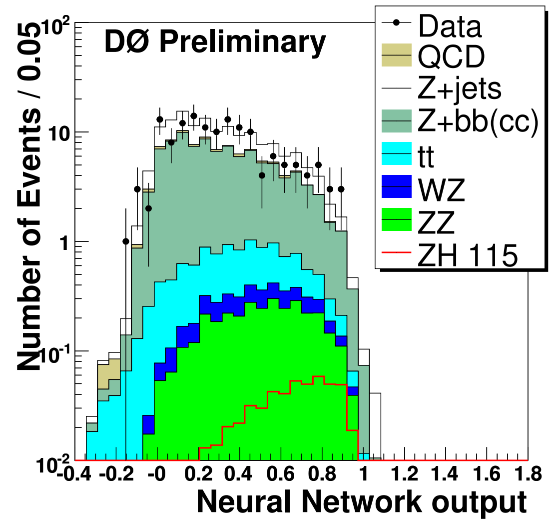
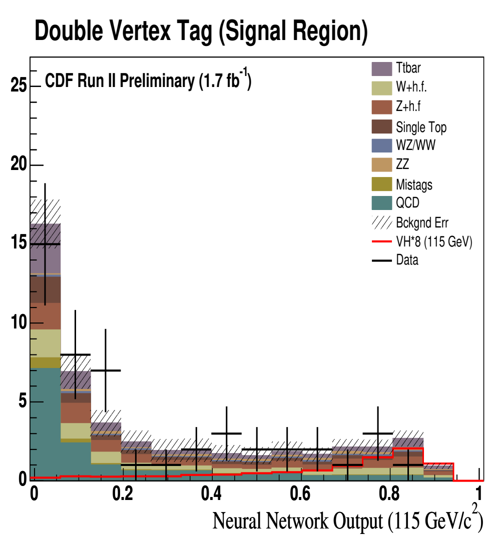


Figure 3: Left: Invariant mass distribution of two btagged jets (CDF). The red/yellow histograms is the invariant mass for the Higgs signal(times 50) after/before the ANN jet correction. Right: ANN output distribution (DØ).

jet or jet mis-reconstruction and/or jet energy mis-measurement that mimic bjet and large $\not\!\!E_T$, respectively. However there is a strong advantage that it gains some acceptance from WH when the lepton is lost in detection. DØ uses 2.1 fb^{-1} (the largest dataset in all analyzes presented in this report) and employs the Boosted Decision Tree (BDT) technique which is basically a machine learning technique to extend a simple cut-based analysis into a multivariate technique by continuing to analyze events that fail a particular criterion. The 95% CL limits are set with respect to the SM prediction as shown in figure 4. At 115 GeV/c^2, the limit is 7.5×SM (8.4×SM expected) [8]. In CDF, two separate ANN have been developed for this analysis. The first focuses on discerning real $\not\!\!E_T$ from fake $\not\!\!E_T$ generated by mis-measurement by using track information. The second ANN is trained to optimize the separation of both ZH and WH events from QCD and $t\bar{t}$ backgrounds as shown in figure 4. Using 1.7 fb^{-1} data, CDF found no excess. Therefore upper limits are set. The limit is 8.0 times over the SM prediction (8.3 expected) at $m_H = 115$ GeV/c^2 [7].



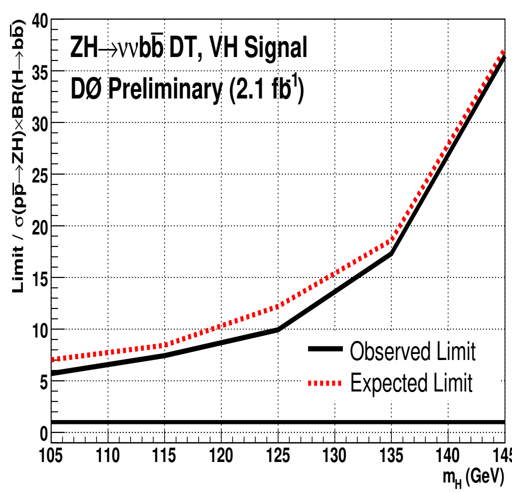


Figure 4: Left: ANN output distribution for 2 btagged events (CDF). Right: Upper limits (relative to the SM prediction) set by DØ $ZH \to \nu\bar{\nu}b\bar{b}$ analysis.

2.4 Search for $WH + ZH + VBF + ggH \to \tau^+\tau^- + 2jets$

All analyzes presented so far use $H \to b\bar{b}$ decay to take an advantage of the high branching ratio while it is smaller for $H \to \tau\tau$ (about 7~8%). CDF however performed the first dedicated search for the SM Higgs boson using τ decay. To recover disadvantage of Higgs decay rate, four signal processes are considered and simultaneously searched as shown in figure 5. The signature is one isolated lepton (τ_{lep}) from leptonic τ decay, one hadronic τ (τ_{had}) from another τ, and two or more jets. No other cuts are imposed in the event selection but instead ANN is trained in order to incorporate possible kinematic variables and their correlations to maximize discrimination power against backgrounds. Main backgrounds are $Z \to \tau\tau + jets$ and jet faking τ_{had} (mainly from $W + jets$ and QCD). After all jet $\to \tau_{had}$ backgrounds are estimated and modeled by data-driven way (using the same sign ($Q(\tau_{lep}) \times Q(\tau_{had}) > 0$) data), three ANN are trained: 1) Mixed signal vs $Z \to \tau\tau$, 2) Mixed signal vs QCD, 3) Mixed signal vs $t\bar{t}$, where mixed signal is a mixture of four signal events. Then given a event, those three ANN scores are calculated and the minimum of the three is selected for making the final ANN distribution. With 2 fb^{-1} CDF data, the simultaneous search was performed but there was no clear excess in signal region as shown in figure 5. Therefore 95% CL limits are set. The result at $m_H = 115$ GeV/c^2 is 30×SM (24 expected) [9].

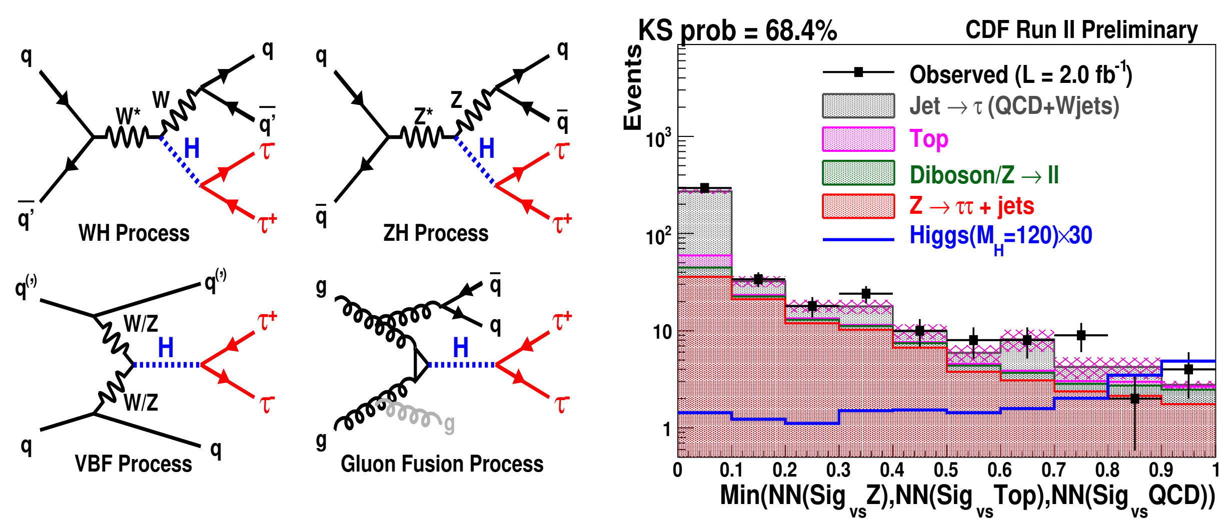


Figure 5: Left: Signal Feynman diagrams used in this analysis. Right: ANN distribution with 2.0 fb^{-1} CDF data. The Higgs signal (times 30) is shown in blue line.

3 Tevatron Combined Limits

Figure 6 shows the current Tevatron limits (at 95% CL) on the Higgs production cross section to the SM predictions. In this combination, all CDF and DØ results are included except for the new CDF's $H \to \tau^+\tau^- + 2jets$ result. Also for DØ $ZH \to \nu\bar{\nu}b\bar{b}$ analysis, only 0.9 fb^{-1} data is currently combined. At $m_H = 115$ GeV/c^2, the observed limit is 6.2×SM (4.3 expected) [10].

4 Conclusions

We have reviewed new preliminary results for the SM Higgs boson searches performed by the CDF and DØ collaborations with 1.0-2.1 fb^{-1} dataset accumulated from $p\bar{p}$ collisions at $\sqrt{s} =$ 1.96 TeV. No signal is found in both experiments and the 95% CL limits are set for a wide range of Higgs mass. At $m_H = 115$ GeV/c^2, combined result now is only about 5 times far from the SM

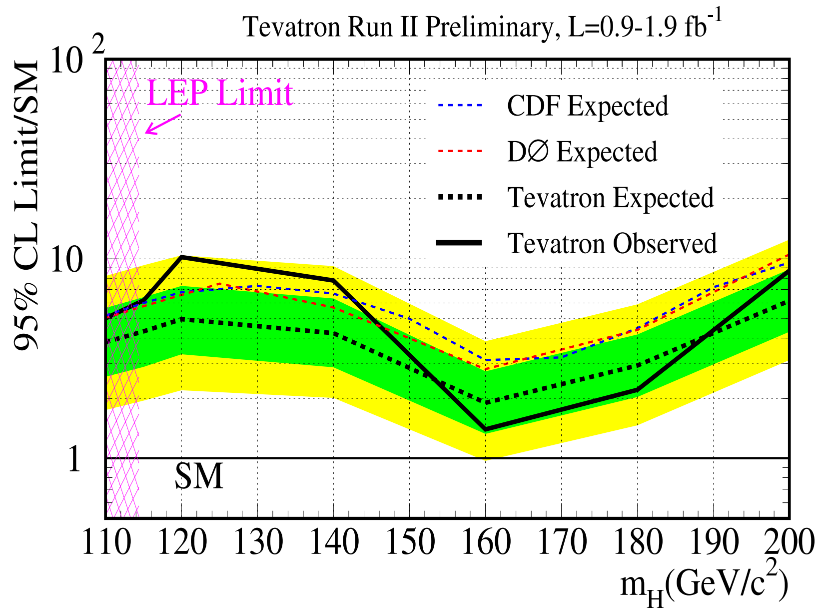


Figure 6: Tevatron combined limits: Ratio of the observed/expected 95% CL limits on Higgs production to the SM predictions as of December 2007. All channels described in this report are combined except for the CDF $H \to \tau\tau + 2jets$ result.

prediction for the exclusion. Furthermore, there are some results not yet combined and also more improvements can be expected and already planned by adding new decay channels, improving b-tagging quality and using advanced technique and so on. On the other hand, CDF and DØ expect to collect at least 6 fb^{-1} data by 2009. Therefore together with expected improvements, there might be a great chance to discover or exclude the SM Higgs even in this challenging low mass region by the end of Run II.

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