

# W/Z+HEAVY FLAVOR PRODUCTION AND THE STANDARD MODEL HIGGS SEARCHES AT THE TEVATRON

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Searches for the Standard Model Higgs in  $WH$  and  $H \rightarrow WW$  channels by CDF and DØ collaborations are presented. The preliminary results are based on  $< 180\text{pb}^{-1}$  of data analyzed by each experiment. Important backgrounds to Higgs searches, such as heavy flavor production in association with massive vector bosons ( $W$  and  $Z$ ) are studied in the process.

## 1 Introduction

Many years of experimental results have shown remarkable consistency with the Standard Model (SM). According to the SM, electromagnetic interaction and weak interaction are manifestations of a hidden symmetry ( $SU(2)_L \times U(1)_Y$ ) which is broken. The electroweak symmetry breaking is achieved through the Higgs mechanism, where the Higgs boson allows for the massive gauge bosons which are responsible for mediating the weak interaction. It can also explain the masses of charged leptons and quarks through Yukawa coupling. Higgs boson plays an essential role in the SM.

Current mass limit on the Higgs from direct searches is  $m_H > 114$  GeV at 95% confidence level (C.L.)<sup>1</sup>. Global fit to precision electroweak observables places an upper limit of  $m_H < 260$  GeV at 95% C.L. Until LHC begins collisions, Fermilab Tevatron is the only accelerator capable of probing that mass range.

### 1.1 SM Higgs Production at the Tevatron

At the Fermilab Tevatron, there are a few accessible production modes of the SM Higgs<sup>2</sup> (Fig. 1). Gluon fusion mode ( $gg \rightarrow H$ ) via a top quark loop is accessible for  $m_H > 135$  GeV, where it is expected to decay dominantly into  $WW$  and background is manageable. For  $m_H < 135$  GeV, associated vec-

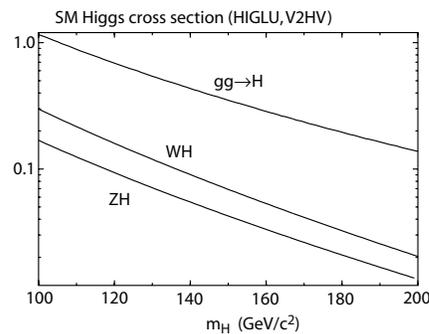


Figure 1. Higgs production cross sections at the Tevatron.

tor boson production modes ( $WH$  and  $ZH$ ) are useful because charged lepton from vector boson decay together with  $H \rightarrow b\bar{b}$  provide a handle against backgrounds.

## 2 W + heavy flavor production and search for the SM Higgs in WH channel

### 2.1 W + $b\bar{b}$ and WH searches at DØ

$W + b\bar{b}$  is an important background to the Higgs production in  $WH$  channel, therefore it is interesting to search for it and study it in detail. DØ searched for  $W + b\bar{b}$  in  $175\text{pb}^{-1}$  of data collected by requiring a high transverse momentum ( $p_T$ ) electron at the trigger level.  $W \rightarrow e\nu$  sample is selected by requiring an isolated electron  $p_T > 20$  GeV in pseudo-rapidity of  $|\eta| < 1.1$  and missing transverse energy  $\cancel{E}_T > 25$  GeV. Events

with any additional leptons are rejected to reduce the  $Z$  background. After requiring  $W$  and two hadronic jets with  $p_T > 20$  GeV and in  $|\eta| < 2.5$ , 2567 events remain in the data.  $2670 \pm 838$  events are expected from  $W(\rightarrow e\nu) + jj$ ,  $Z \rightarrow ee$ ,  $Z \rightarrow \tau\tau$ , inclusive  $W \rightarrow \tau\nu$ ,  $t\bar{t}$ .  $W + jj$  is simulated using ALPGEN leading-order (LO) event generator, where partons are passed through PYTHIA showering with full detector simulation. Next-to-leading (NLO) production cross sections are used for background processes. Instrumental background due to fake electrons is estimated from the data.

A  $b$ -tagging algorithm is used to identify the jets originating from  $b$ -quarks. Jet lifetime impact-parameter (JLIP) tagging algorithm which makes use of the distribution of impact parameters of the charged tracks associated to a jet in order to calculate the probability of the jet to be consistent with a jet without significantly displaced tracks. After requiring that there be two jets tagged with the JLIP algorithm, 5 events remain. This is in good agreement with  $6.9 \pm 1.8$  total events expected, out of which 3.8 events are expected to come from  $t\bar{t}$  and single top productions. In order to reject  $t\bar{t}$  backgrounds, exactly 2 jets are required to be present in the event. Two events remain after this requirement whereas  $2.5 \pm 0.5$  events are expected. 1.4 events are expected to be from  $W + b\bar{b}$ . Since no significant excess is observed above the other backgrounds,  $W + b\bar{b}$  production cross section upper limit is set at 20.3 pb at 95% C.L.

The result above can be translated into an upper limit on  $\sigma(WH) \times BR(H \rightarrow b\bar{b})$ . A simple counting experiment is performed. For a Higgs boson of  $m_H = 115$  GeV, we measure approximately 14% relative mass resolution from Monte Carlo simulation. The mass window in which counting experiment is done is 1.5 times the mass resolution on either side. 0 event is observed in the window and the preliminary upper limit is  $\sigma(WH) \times BR(H \rightarrow$

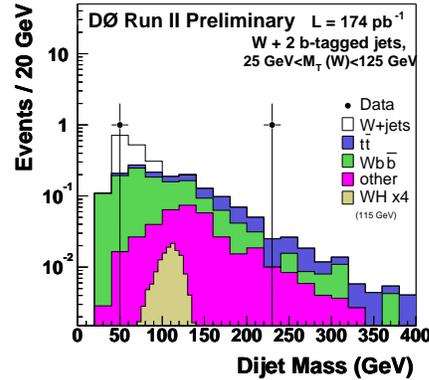


Figure 2. Dijet mass spectrum of  $b$ -tagged jets from  $D\bar{O}$ .

$b\bar{b}) < 12.4$  pb at 95% C.L.

## 2.2 Higgs Search in $WH$ at CDF

CDF searched for the Higgs in  $162 \text{ pb}^{-1}$  of data combining both the electron and muon decay channels of the  $W$ . To select  $W + 2$  jets events, either an electron or muon of  $p_T > 20$  GeV in the central rapidity region,  $\cancel{E}_T > 20$  GeV, and two jets of  $E_T > 15$  GeV are required. Events with additional high  $p_T$  tracks are removed to reduce the  $Z$  background. In order to reduce the backgrounds from  $t\bar{t}$ , sophisticated cuts are applied to the third and the fourth leading  $E_T$  jets.

A secondary vertex  $b$ -tagging algorithm is applied to the exclusive  $W + 2$  jets events, requiring at least a single  $b$ -tag. 62 events are observed and  $67 \pm 9$  events are expected. Approximately 32.4 events are expected from  $W + b\bar{b}$ ,  $W + c\bar{c}$ , and  $W + c$ .  $W + j$  mis-tags contribute 14.1 events.  $t\bar{t}$  and single top backgrounds are small (8.9 events) due to optimized cuts on the jets.

The performance of the  $b$ -tagging used in the analysis has lower efficiency but a much smaller mis-tag rate compared to  $D\bar{O}$   $b$ -tagging algorithm. Good signal significance is obtained by requiring that at least one jet be tagged. It is a good complementary method to the double tagged analysis by  $D\bar{O}$ .

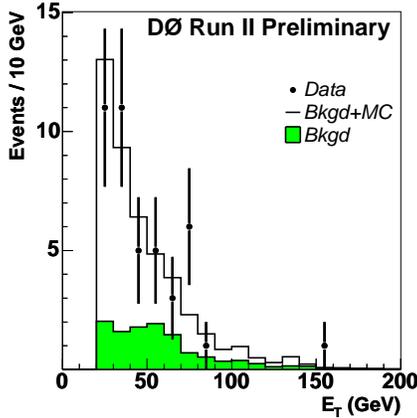


Figure 3. Jet  $E_T$  distribution of  $b$ -tagged jets in  $Z + b$ -jet events. The background shown in green is from mis-tagged light-jets and instrumental backgrounds.

The signal acceptance is moderately flat between  $110 < m_H < 150$  GeV at  $1.5 \sim 1.7\%$  in this analysis. In lack of any excess of events, a preliminary limit on  $\sigma(WH) \times BR(H \rightarrow b\bar{b})$  is set as a function of the  $m_H$  (Fig. 5).

### 3 $Z + b$ inclusive production

Inclusive production of  $Z + b$ -jet is a background to the Higgs search in  $ZH$  mode where  $H \rightarrow b\bar{b}$ . It is also a probe of  $b$ -quark parton distribution function in the five-flavor scheme<sup>3</sup>.

DØ looked for an evidence of heavy flavor production in association with the  $Z$  boson. In particular, a ratio inclusive production cross-sections  $\sigma(Z + b\text{-jet})/\sigma(Z + \text{jet})$  is measured using  $180\text{pb}^{-1}$  of data. Samples triggered with single lepton and dilepton triggers are used. In the ratio measurement, trigger efficiencies and luminosity uncertainties cancel identically. To first order, it is not sensitive to experimental effects such as jet energy scale, jet energy resolution, and jet reconstruction efficiency. However, it is sensitive to any differences between light-jet and  $b$ -jet responses in the detector.

3458 events remain after  $Z + \text{jet}$  events

are selected by requiring the presence of two high  $p_T > 15$  GeV electrons or muons, dilepton invariant mass consistent with that of  $Z$ , and at least one hadronic jet of  $p_T > 20$  GeV and  $|\eta| < 2.5$ .

42 events remain after applying secondary vertex tag with 8.3 events expected to come from instrumental background which is estimated from the data. Events left after background subtraction is a combination of  $Z + b$  ( $N_b$ ) and mis-tagged events from  $Z + c$  ( $N_c$ ) and  $Z + \text{light-jets}$  ( $N_L$ ). The efficiencies for tagging  $b$ -jets ( $\epsilon_b$ ) and light-jets ( $\epsilon_L$ ) are measured from the data. Tagging efficiency of  $c$ -jets ( $\epsilon_c$ ) is measured in simulated events and scaled by  $(\epsilon_b)_{Data}/(\epsilon_b)_{MC}$ . Two equations relating the number of events before  $b$ -tagging and after  $b$ -tagging with  $N_b$ ,  $N_c$ , and  $N_L$  together with the  $\epsilon$ 's can be written. To solve the system of equations, we assume from theory the ratio of  $N_c/N_b = 1.69$ .

The preliminary result is  $\sigma(Z + b\text{-jet})/\sigma(Z + \text{jet}) = N_b/(N_b + N_c + N_L) = 0.024 \pm 0.005(\text{stat}) \pm 0.005(\text{syst})$ , where the dominant sources of systematic uncertainties are  $b$ -tagging efficiency and background estimation. The measurement is in agreement with the NLO theory prediction of  $0.018 \pm 0.004$ .

### 4 Search for $H \rightarrow WW$

Both CDF and DØ presented the measurements of  $WW$  production cross section at this conference, which are in good agreement with the Standard Model prediction. The Standard Model  $WW$  production is one of the major irreducible backgrounds in the search for Higgs in the  $H \rightarrow WW$  channel. Some separation between the  $WW$  SM production of  $WW$  and  $H \rightarrow WW$  can be attained by the fact that  $H$  is a spin 0 object, hence, the  $W$ 's will have spins relatively oppositely-aligned. The charged leptons from the  $W \rightarrow \ell\nu$  in  $H \rightarrow WW$  will have a smaller azimuthal opening angle ( $\Delta\Phi_{\ell\ell}$ ) compared to the  $WW$

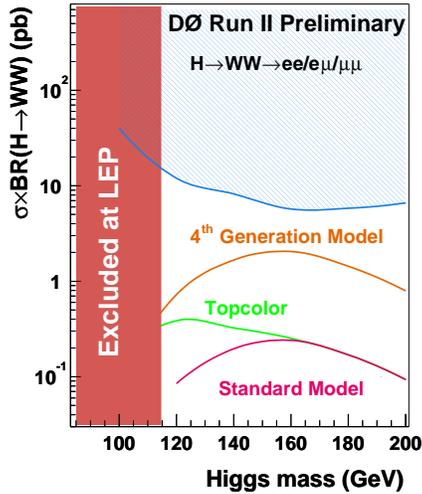


Figure 4. DØ results on  $\sigma \times Br(H \rightarrow WW)$ .

production.

#### 4.1 DØ

DØ analyzed  $147 \sim 177 \text{ pb}^{-1}$  of data by requiring 2 oppositely charged leptons ( $e$  or  $\mu$ ), large  $E_T$  for the presence of a neutrino in the event, cut on dilepton mass or minimal transverse mass, scalar sum of lepton  $p_T$  and missing  $E_T$ . Finally, events with jets are rejected. The selection is designed to optimize on signal significance (for each  $m_H$ ) by rejecting background from  $Z$ ,  $W + jets$ , and  $t\bar{t}$ . Finally, counting experiment is performed in the region of small  $\Delta\Phi_{\ell\ell}$ . No significance excess above the background is observed and the upper limit on  $\sigma \times Br(H \rightarrow WW)$  as a function of the  $m_H$  is set (Fig. 4).

#### 4.2 CDF

Event selection of the CDF analysis is similar to that of DØ. The cut on dilepton mass is  $M_{\ell\ell} < m_H/2$ . Limit on  $\sigma \times Br(H \rightarrow WW)$  as a function of  $m_H$  is extracted by performing likelihood fits to the observed  $\Delta\Phi_{\ell\ell}$  distribution, and it is shown in Fig. 5.

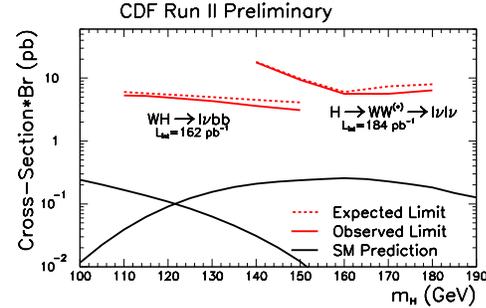


Figure 5. Summary plot of CDF results on the SM Higgs searches.

## 5 Summary and Outlook

Both CDF and DØ experiments have started to search for the SM Higgs boson. Studies of rare but irreducible SM backgrounds are also underway. The results presented does not make use of any advanced analysis techniques. Use of multivariate methods is expected to improve the sensitivity. With approximately  $2 \text{ fb}^{-1}$  of luminosity, Fermilab Tevatron is expected to probe the range of  $m_H$  excluded by the LEP 2 experiments. With the projected integrated luminosities of  $4 \sim 8 \text{ fb}^{-1}$  to be delivered to each experiment by 2009, exciting period lies ahead of us in the quest for the Higgs.

## References

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